STRUCTURE
OF
TYPICAL AMERICAN OIL FIELDS

Published with the aid of a fund established
by the New York committee for the mid-year
meeting of the Association, November, 1926

STRUCTURE
OF
TYPICAL AMERICAN OIL FIELDS

A SYMPOSIUM ON THE RELATION OF OIL ACCUMULATION TO STRUCTURE

THIRTY PAPERS ON THE PROGRAM OF THE TWELFTH ANNUAL CONVENTION OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS AT TULSA, OKLAHOMA
MARCH 24, 25, AND 26, 1927

VOLUME I
1929

PUBLISHED BY
THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
TULSA, OKLAHOMA, U.S.A.

LONDON: THOMAS MURBY & CO., 1, FLEET LANE, E.C. 4

Published March, 1929

Composed and Printed By
The University of Chicago Press
Chicago, Illinois, U.S.A.

PREFATORY NOTE

Modern petroleum geology in the United States had its beginning in the first decade of the present century when the United States Geological Survey commenced to map the structure of the rocks in and near oil fields in order to discover the various types of structural conditions under which oil and gas are trapped. The earlier methods of observational mapping, pedometer and odometer compass traverses with hand level, and aneroid barometer determinations of relative elevations, were gradually supplanted by the introduction of the telescopic alidade and planetable about 1909. Between 1913 and 1925 a combination of observational and instrumental methods of investigation led to the discovery of many oil fields, especially in the Mid-Continent region.

Structural geology has evolved as a branch of the broader science far more rapidly than have methods of mapping the attitude of rocks at the surface. Spindletop, in 1901, was an enigma to geologists. At about the same time, in California, drilling near seepages led to the discovery of very extensive fields; yet the attitude of the surface rocks, where evidence was available, did not indicate structure then known to be favorable for the accumulation of petroleum.

Hence it became obvious that the structure of an oil field is properly considered with reference to the upper surface of the reservoir body, and that the rocks at the surface of the ground may have a very different attitude. With modern methods of geological mapping, diamond drilling for structure, sampling and studying all formations encountered in drilling wells, measuring the straightness of these holes, airplane mapping, and geophysical prospecting, structural geology has become more important in its functions in the recovery as well as in the discovery of oil and gas.

These volumes are designed to afford authoritative and modern descriptions of the structure of typical oil fields in the United States. Emphasis is placed upon fields other than salt domes, as these have been described in an earlier volume. Each field is described by an author who is intimately familiar with the available data. The relationship of structure at the surface and at depth for different terranes is clearly set forth wherever the strata are not parallel. It is hoped also that modern conceptions of structural features, such as buried hills, may be made obvious.

Unfortunately no compilation is complete. The co-operation of the authors in writing these papers, together with the painstaking and efficient care of J. P. D. Hull in compiling and editing them, is sincerely appreciated. May the volumes stimulate the progress of structural studies in petroleum geology.

SIDNEY POWERS

TULSA, OKLAHOMA
July, 1928

CONTENTS

LIST OF FIGURES

ARKANSAS

CALIFORNIA

INDIANA

KANSAS

NEW MEXICO

OHIO

OKLAHOMA

LIST OF PLATES

IRMA OIL FIELD, NEVADA COUNTY, ARKANSAS[1]

L. P. TEAS[2]
Houston, Texas

ABSTRACT

The Irma field is situated in Nevada County, Arkansas. At present sixty-five wells produce 2,600 barrels daily from the Nacatoch sand at about 1,200 feet. Irma is a fault field although no deep production has yet been found. The faulting and doming are clearly shown on the surface. The average throw of the fault is about 400 feet. The closure along the fault is about 50 feet. The accumulation of the oil here is due to faulting and the closing of the monoclinal structure against the fault.

Introduction

The Irma oil field, named from a locality 3 miles northwest of the field, is situated in T. 14 S., R. 21 W., and T. 14 S., R. 20 W., in the south-central part of Nevada County, Arkansas. It occupies portions of Sections 1, 2, 9, 10, and 11 of T. 14 S., R. 21 W., and the recent eastward extension lies in Section 6 of T. 14 S., R. 20 W. The field is served by the Reeder Railroad, which connects with the Missouri Pacific Railroad at Reeder, about 20 miles northwest of the field. Waldo, a town on the Cotton Belt Railroad, lies 13 miles south. The field is 4 miles long, northeast and southwest, and has an average width of ½ mile.

Oil at Irma was found first by Ames and Zingg in T. P. Waters No. 1, on October 17, 1921. The discovery well is located in the center of the west side of the NW. ¼ of Sec. 11, T. 14 S., R. 21 W., on an 80-acre tract given Ames and Zingg by Like Watkins and his associates for a well. The cap of the Nacatoch sand was struck at 1,166 feet and the hole carried to 1,192 feet. After this well was bailed, oil having a gravity of 14.4° slopped over the casing head at the rate of 5 barrels a day until March, 1923, when it was put on the beam and pumped 25 barrels daily.

Topography and Drainage

The Irma field is hilly, with an average altitude for the hilltops of 350 feet, and for the valleys, of 275 feet. The maximum relief is about 135 feet. There are many small streams, most of them flowing into Caney Creek, which flows northward across the center and highest structural

[1] Presented by title before the Association at the Tulsa meeting, March 26, 1927. Manuscript received by the editor, October 3, 1927.

[2] Geologist, Humble Oil and Refining Company, Houston, Texas.

part of the field. A branch of Sanders Creek crosses the west end of the field. The Gurdon quadrangle topographic sheet of the United States Geological Survey (1901) shows the topography of the area, and a soil survey map of Nevada County is in preparation.

Geology

GENERAL STATEMENT

The Irma field presents several interesting geological features. It is a faulted monocline lying against the south side of a graben. The surface formations (Fig. 1) are of Eocene age, although a thin, irregular veneer of gray sand with a few scattered pebbles probably represents deposits of Pleistocene age. The cross-bedded sands and clays of the Wilcox formation are exposed against the south fault along the crest of the monocline and abut against ferruginous, selenitic clays of the Lower Claiborne. On the high side of the fault, and forming a thin irregular crescent around the Wilcox, lie the irregularly weathered glauconitic beds of the Cane River formation, which is the lowest formation of Claiborne age. These in turn are succeeded above by gray sands and sandy clays which can be correlated with the Queen City beds of East Texas.

STRATIGRAPHY

SURFACE

The general section for south-central Arkansas is given in Table I.

In view of the variable character of the Wilcox and Claiborne formations of Arkansas, a detailed section that will represent large areas is out of the question. However, in the foregoing section the divisions that have been indicated appear to carry through from the Texas state line to the Ouachita River bottoms with fair regularity. The distinctive weathering of the ferruginous divisions perhaps is one of the biggest helps in establishing the section. Variations in the thicknesses of the sand and clay members of the Claiborne perhaps may be more readily accounted for on the assumption that the eastern arm of the Claiborne sea extending part way up the Mississippi embayment in eastern Arkansas was separated by a shallow-water area from the East Texas arm of the Claiborne sea. This barrier area included Nevada, Columbia, Miller, Lafayette, and part of Ouachita counties, and it is in this region that sand has replaced some of the marine clay zones exposed farther west and farther east.

The ferruginous beds lying between the lower sands below, and the Sparta sand above, can be correlated with the glauconitic horizon well exposed at Bowie Hill, in northeastern Cass County, Texas. This corre-

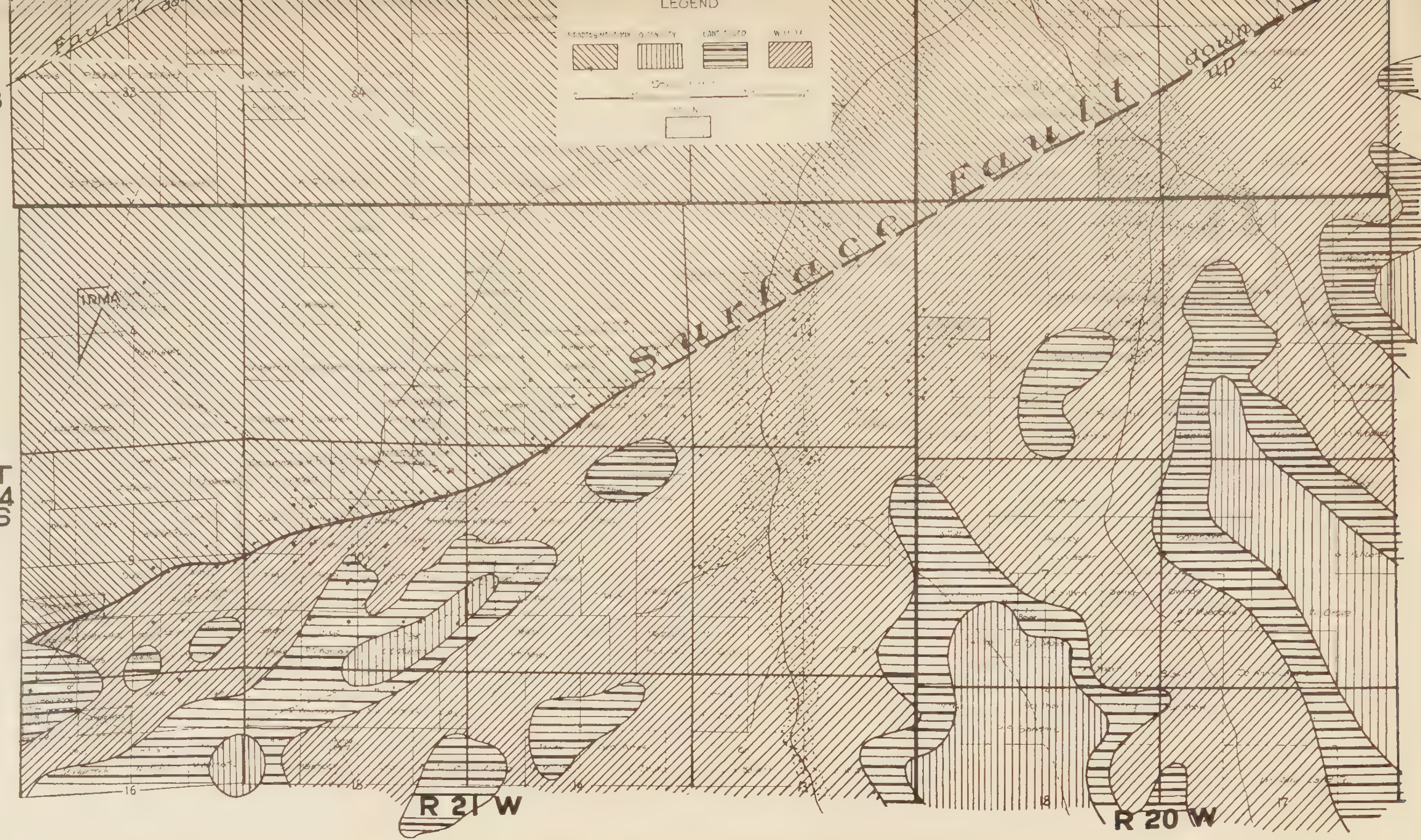


FIG. 1.—Areal geological map of the Irma, Arkansas, oil field.

lation cannot be supported by paleontology due to the lack or indefinite character of the fossil evidence in Cass County and in Arkansas, but the field evidence indicates this correlation. According to G. M. Knebel,[1]

TABLE I

General Tertiary Section, South-Central Arkansas

surface formations

	Age	Formation	Thickness in Feet	Characteristics
Eocene Series	Claiborne	Yegua	250, maximum	Gray and yellowish sands, weathering red, and gray and chocolate clays with leaf impressions and silicified wood. Gray and pink siderite concretions and a few bog-iron ore beds. Yegua generally weathers pinkish-brown and leaves somewhat sandy soil
		St. Maurice	50+, thickens eastward	Generally ferruginous gray and chocolate clays and ferruginous sandy clays. Becomes like Yegua northward into Arkansas, west of Camden, but east of Camden it can be traced by its iron content
		Sparta sand	200, thins eastward	Mostly gray and yellowish sand, weathering red, with local sandstone lenses and concretions. Some siderite and silicified wood. Near center of formation greenish-gray and chocolate clay 50 to 100 feet thick. Thickening of clays eastward, above and below, reduces thickness of Sparta east of Camden
		Ferruginous clay zone [Mt. Selman]	50+, thickens eastward	Consists of one main ferruginous, glauconitic clay zone with siderite concretions separated by gray sand and sandy clay characterized by red weathering
		Lower sands [Queen City]	125–300, thins eastward	Gray and yellow sand and gray and chocolate clay with leaf impressions; sand locally indurated to ferruginous sandstone
		Cane River clays	50±	Upper 10 feet is glauconitic clay with deep red to yellow ferruginous weathering. Below this are gray and chocolate ferruginous clays and sandy clays
	Wilcox	Upper sand Middle clays Middle sand	175 50 175	Highly cross-bedded gray and yellowish sands, and gray and chocolate clays, with siderite boulders weathering to limonite. Beds of lignite. A definite siderite zone about 125 feet below the top
		Sandy clays and sand	200	Quartzitic ledges occur locally above the siderite zone and near the base of the formation
	Midway		450	Dark blue non-calcareous clays, with boulders of siderite followed by brittle blue clays. Basal 35–45 feet is calcareous clay. Near top a bed of siderite concretions shows cone-in-cone structure

[1] Oral communication.

the beds at Bowie Hill appear to be the equivalent of the main green sand beds at San Augustine, Texas, generally known as the Mount Selman.

The character of these lower clays may be seen along the road on the east line of Sec. 9, T. 14 S., R. 21 W., from the center of the section north, and along the Prescott road to Irma. The beds are here faulted down. They may be seen in their normal position between Waldo and Magnolia and on the Waterloo road north of Waldo.

The sand overlying this ferruginous clay zone can be logically correlated with the Sparta sand of the Louisiana section, and the sand below may be referred to the Queen City sand, which overlies the Cane River formation along the Texas-Arkansas line north of Louisiana. These correlations are merely suggested, but it is hoped that these divisions will

TABLE II

Section in Northeast Part of Section 5, T. 14 S., R. 20 W.

Queen City (?)	Upper gray sands . . . . . 20 feet
Cane River clays	Glauconitic clay, weathering to red-brown ferruginous, platy material . . . . . 6 feet Ferruginous sandy clay with platy limonitic material . . . . . 22 feet Platy ferruginous limonitic clay . . . . . 13 feet
Wilcox	Sandy clay and sand . . . . . 10+feet

be recognized and given appropriate names when the geology of Arkansas is mapped in detail.

The correlation of the glauconitic beds fringing the Irma structure with the Cane River of Louisana may be criticized, since here again no fossil evidence for this association has been found. However, the character of the beds and the fact that they occupy almost the same position in the section as at their exposures in Louisiana near Hosston and Vivian suggest this view.

The Cane River formation is best seen along the road in the northeast part of Sec. 5, T. 14 S., R. 20 W. (see Table II).

Near the field the typical thin platy limonitic fragments of Cane River can be seen exposed in gullies and along the road. The gray sand capping may belong to the Queen City, or may be a recent deposit.

Owing to faulting and deposits of later sand and gravel, a complete section is rare in south-central Arkansas. Perhaps the best section of the Claiborne sands and clays occurs from old Lunet in northeast Ouachita County, south of Camden, and then along the Mount Holly road for 10 or 15 miles, or along the El Dorado road for 8 miles.

SUBSURFACE

The section in Table III gives the combined surface and subsurface geological formations in the Irma region.

The lower part of the foregoing section is of particular interest. The Brownstown formation seems to have its ordinary thickness of 200 feet at Irma. It is a gray to bluish slightly sandy clay with numerous fossils.

TABLE III

GEOLOGICAL SECTION AT IRMA, ARKANSAS*

System	Formation	Thickness in Feet	Character
Eocene	Claiborne	0–500	Sands, clays, some glauconite and siderite
	Wilcox	600	Gray, cross-bedded sands and clays with lignite beds; quartzite and siderite boulders
	Midway	450	Dark blue non-calcareous clays with siderite boulders; calcareous clay at base
Upper Cretaceous	Arkadelphia	100	Calcareous clay and shale
	Nacatoch	310	Gray and green calcareous sand with clay and marl at base
	Saratoga	75	White, highly fossiliferous chalk and marl
	Marlbrook	60	Chalky marl and gray clay
	Annona	165	Hard white chalk, chalky marl, and gray clay
	Ozan	200	Sandy micaceous marl and clay
	Buckrange sand	20	Glauconitic sand and sandy clay
	Brownstown	200	Dark gray calcareous, fossiliferous clay
	Tokio	80	Fossiliferous clays, sandy clays, sand and some volcanic ash
	Woodbine	250	Clay-cemented sand and sandy shale; volcanic ash and coarse ash-cemented sands, green sands, some red shale and sand
Lower Cretaceous	Trinity	2,000+	Red shales, sands, and some fossiliferous (DeQueen) limestone. Some celestite occurs probably at the anhydrite horizon of Louisiana

* Upper Cretaceous formation names in part from Carl H. Dane, "Oil-Bearing Formations of Southwestern Arkansas," *U. S. Geol. Survey Memorandum for the Press*, September 10, 1926.

It is succeeded below by the Tokio beds (Austin), which have thinned to about 80 feet. These beds are mainly sandy shales and medium-grained sands with a few fossiliferous streaks of clay. Some volcanic ash also occurs in the Tokio. As at the outcrop, no Eagle Ford exists at Irma so far as known, although it has been identified in North Louisiana.[1] The Tokio, therefore, lies unconformably upon the Woodbine.

[1] By Miss A. C. Ellisor, on the basis of *Foraminifera* in several wells, and by L. W. Stephenson from fossils blown from the Texas-Standard, Sutherlin No. 1, Sec. 18, T. 12 N., R. 14 W., De Soto Parish.

The Woodbine is well developed at Irma and is at least 250 feet thick. It consists of sand, brown and gray non-marine shales, and sandy shales with lignitic material. The sands are coarse-grained and cemented with volcanic ash. Beds of impure volcanic ash also occur. Toward the base the sands become coarser and even conglomeratic and tuffaceous, with ash cement. The Woodbine, as the basal sand of the Upper Cretaceous, represents a unique deposit, since in Arkansas, and to a lesser extent in Louisiana, material ejected from active volcanoes at the close of the Lower Cretaceous period is responsible for much of its thickness. These volcanoes spread their ejecta uniformly over the beveled edges of the Trinity beds, partially, at least, under water. Streams re-worked the material until the Woodbine covered a very large area. Subsequent erosion, prior to the deposition of the Tokio, may have removed some of the upper part of the Woodbine and uncovered areas previously covered with Woodbine, but still a widespread blanket of clastic material remained, which is strictly a basal deposit of Woodbine age.

At Irma the upper beds of the Trinity consist of fine-grained gray and greenish sand, and red and bluish clays. However, 10 miles southwest, at Falcon, therefore farther toward the center of the Trinity basin, the basal conglomeratic beds of the Woodbine rest upon the De Queen limestone. Due to the fact that on the southwest Trinity beds were truncated by erosion, in general, toward the east, successively older beds should form the floor upon which the Woodbine was deposited. Local structural "highs" in the truncated Trinity of course produced variations. Since at Falcon and at Stephens the De Queen limestone seems to be higher than in the Magnolia's Johnson well four miles south of the Irma field, it is possible a saddle may exist in the Trinity at Irma.

STRUCTURE

The Irma field occupies the narrow crest of a monocline cut on the north side by a fault having a throw from 325 to 470 feet. So far as determined, the highest part of the structure lies along the fault, so that the fault is responsible for much of the closure. The closure against the fault may exceed 70 feet, but the productive closure, so far as outlined by drilling, is about 50 feet (Figs. 2 and 3).

The oil and gas accumulation here is clearly a result of the closure of the monocline against the fault, and the gas, oil, and water are separated in accordance with the anticlinal theory. The fault itself, apparently, has also had much to do with the accumulation of the oil and gas.

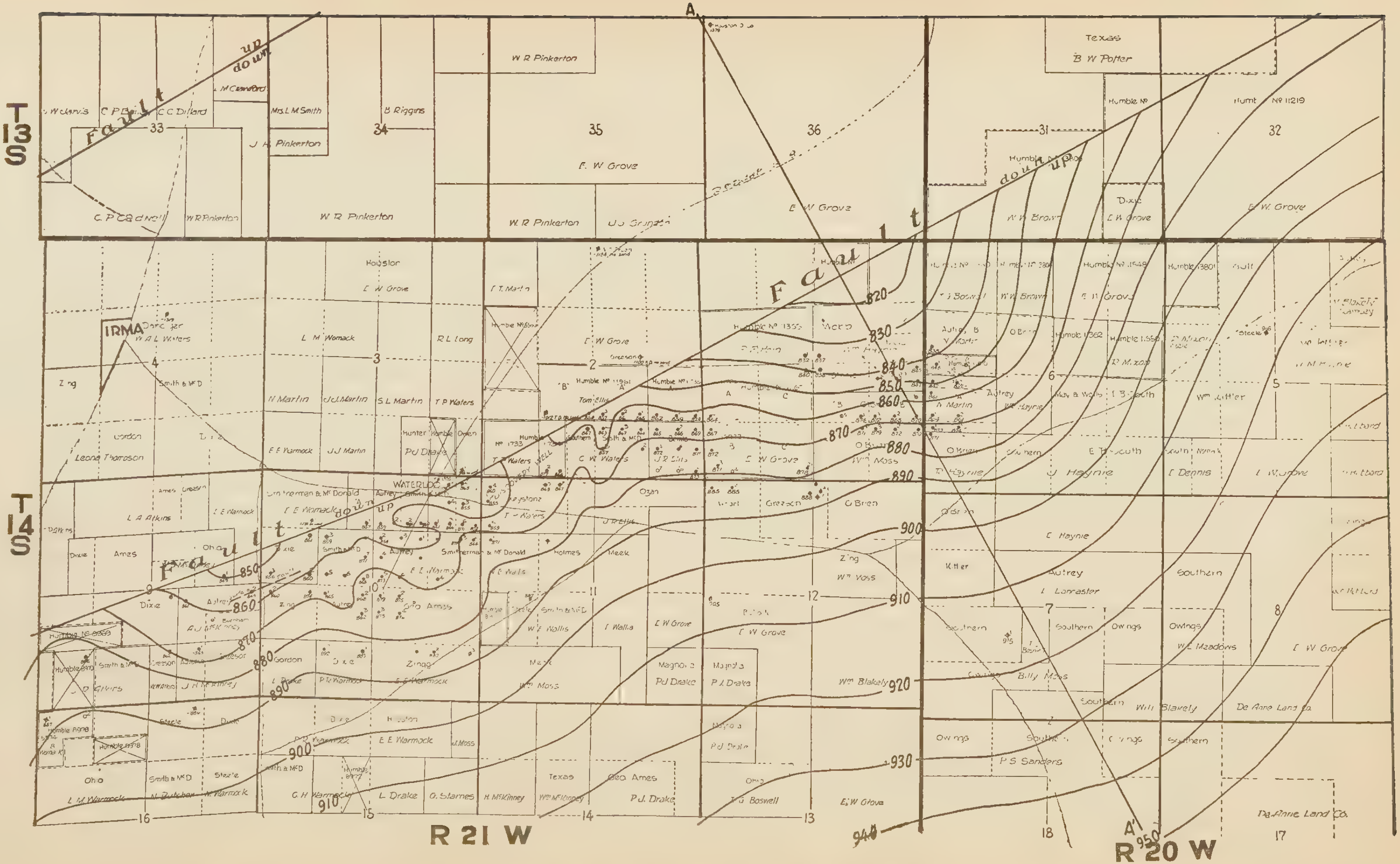


FIG. 2.—Structural geological map of the Irma field. Contours drawn on top of the Nacatoch sand below sea-level.

Subsequent note.—Since the completion of this map the Dixie Oil Company's Grove No. 1, in the southwest corner, SE. ¼, SE. ¼, Sec. 31, T. 13 S., R. 20 W., near the northeast end of the field, has been drilled in the fault graben. Total depth of well is 1,582 feet, elevation 242 feet, and top of the Nacatoch probably a little above 1,540 feet, or about 425 feet below normal. The Irma fault therefore bends a little south from the last control point, near the center of Sec. 2, T. 14 S., R. 21 W., 2¼ miles southwest of the Dixie well.

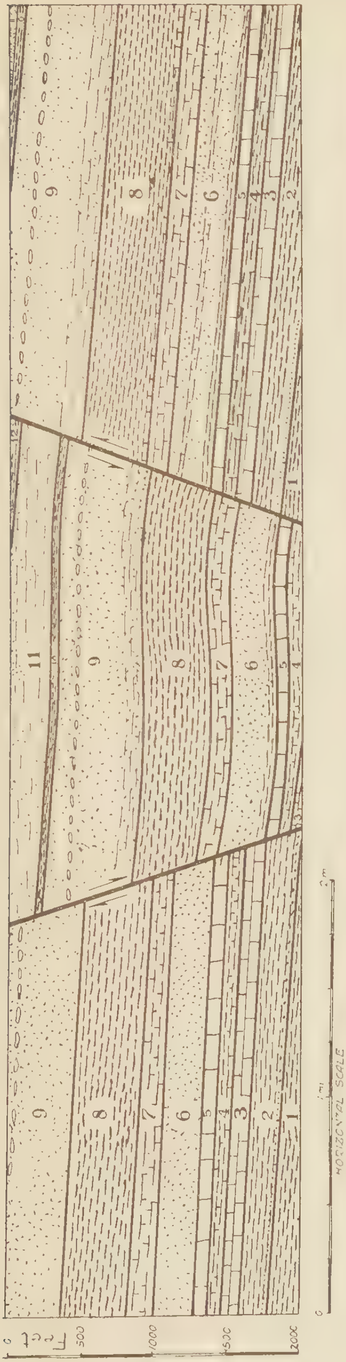


FIG. 3. Geological cross section through the Irma field along line A-A′, and extending about 3 miles northwest beyond the limits of the map (Fig. 2). 1, Brownstown marl. 2, Ozan formation with Buckrange sand at base. 3, Annona chalk. 4, Marlbrook marl. 5, Saratoga chalk. 6, Nacatoch sand. 7, Arkadelphia marl. 8, Midway. 9, Wilcox. 10, Cane River. 11, Queen City. 12, Mount Selman.

On the surface (Fig. 1), from the southwest corner of Sec. 9, T. 14 S., R. 21 W., to Sec. 28, T. 13 S., R. 20 W., the Wilcox on the south or upthrown side of the fault lies against the down-faulted Claiborne. The Cane River abuts the down-faulted Claiborne near the southwest part of Sec. 9, T. 14 S., R. 21 W., and parallels the fault for 3 miles where the lower terrain and higher structure broaden the area of the Wilcox outcrop. In Sec. 28, T. 13 S., R. 20 W., the Cane River again approaches close to the fault, but does not seem to abut against it as it does on the southwest.

On the north side of the north fault flat ledges and fragments of quartzite occur. This quartzite appears to have no connection with the faulting, as quartzite of this character normally, but locally, occurs about 100 feet below the top of the Wilcox, along its outcrop area in Arkansas. The quartzite particularly referred to is in Secs. 26, 31, and 32, T. 20 S., R. 14 W.

The faulted area consists of a graben with a width slightly exceeding two miles if measured between the intersections of the faults with the top of the Nacatoch sand. The hade of the south fault against which the field lies is about 60° toward the north, so that the width of the graben on the surface is about $2\frac{1}{2}$ miles. That the floor of the graben is

irregular and therefore presents possibilities of closed structures is evidenced by the different depths at which the few deeper wells in the graben struck the Nacatoch. The recent eastern extension of the field indicates that the anticline broadens into a dome at the east end of the fault where the productive width in the Nacatoch is about a mile. Gas was found in three wells on the west end (west side of Section 10), and at the east end in Sections 1 and 2.

On the surface (Fig. 1) the fault may be traced by following the contact between the Wilcox sand on the south and the ferruginous, concretionary, selenitic, red-weathering clays of the down-thrown Lower Claiborne on the north. The actual fault break may be seen on the west side of the road at the center of the east line of Sec. 9, T. 14 S., R. 21 W. Near the base of the north slope of a hill, cross-bedded sands of the upper part of the Wilcox, colored reddish by waters from the fault, are in contact with thin-bedded chocolate, selenitic, red-weathering clays of the Lower Claiborne. A thin parting of limonite, $\frac{1}{4}$ inch thick, represents the actual plane. The strata of the down-thrown clays show a drag as great as 60° sloping northward from the plane for about 10 feet. The hade of the fault measured here averages about 60°. The horizontal distance from the surface trace to the Nacatoch trace is 950 feet, which represents an angle of 53° corresponding fairly closely to the hade actually measured in the field. A fault is also well exposed on the road about $\frac{1}{4}$ mile south of the center of Sec. 28, T. 13 S., R. 20 W.

The Irma fault belongs to an extensive fault system extending in a general northeasterly direction through southwest Arkansas. This system enters southwest Miller County from Louisiana and passes through Miller, Lafayette, and Nevada counties. The age and characteristics of the faulting resemble those of the Mexia system in Texas. These faults were probably produced by tensional stresses caused by the accumulating Tertiary sediments and complicated by the influence of the rising Sabine uplift. The breaking occurred along the margin of the Tertiary sea. The faulting probably commenced during Midway time, for the Midway is generally a little thicker in the graben wells in other faults southwest of Irma, and continued through Claiborne time with the maximum activity probably in Miocene time.

There is no direct evidence at Irma that the Midway is thicker than normal in the graben, but some of the wells along this faulting system farther southwest, in the graben, show a thickening of the Midway from 70 to 100 feet. However, on the east in Sec. 15, T. 14 S., R. 19 W., Humble Oil and Refining Company's Lancaster No. 1, drilled in a fault graben, en-

countered the Wilcox and Midway with normal thickness, although about 300 feet lower than normal.

The wells drilled in the Irma graben, or those that have crossed the fault into the graben, are given in Table IV.

TABLE IV

WELLS DRILLED IN THE GRABEN AT IRMA

Well	Location			Top Nacatoch below Sea-Level (in Feet)	Throw in Feet from Crest of Structure
	Sec.	T.	R.		
Houston Oil Co.'s Grove No. 1.	36	13	21	1,379	337
Danciger Oil Co.'s Waters No. 1.	4	13	21	1,319	489
Smitherman and McDonald's T. P. Waters No. 2..........	10	14	21	Cut fault plane below Nacatoch	
Smitherman and McDonald's E. E. Womack No. 1........	10	14	21	1,024, no sand	
Owings' T. P. Waters No. 1....	3	14	21	966, no sand	
Wooten's Ellis No. 1...........	2	14	21	1,012, no sand	
Greeson's Grove No. 1..........	2	14	21	1,100, no sand	
W. F. Fruen's Grove No. 1......	2	14	21	1,184, no sand	
Steele's Martin No. 1...........	13	14	22	1,140. This well probably in graben, near its west end	

Producing Sand

The Nacatoch sand produces oil at Irma. This sand is characteristically limy and interspersed with hard caps and beds of shales, although the sand directly beneath the first cap is generally porous for 15 or 20 feet. The Nacatoch formation has a total thickness at Irma of about 310 feet.

The following records show the character of the producing horizon:

C. F. Steel *et al.*, Haynie No. 1, Sec. 1, T. 14 S., R. 21 W. Producing 35 mil. cu. ft. gas.

1073–90	Lime rock
1090–1115	Hard gas sand
1115–18	Gumbo and shale
1118–19	Cap
1119–23	Oil sand (water also)

Humble O. & R. Co.'s Grove B-3, Sec. 1, T. 14 S., R. 21 W.

1130–41	Gumbo
1141–42	Gas sand
1142–44	Sand
1144–45	Sandy shale and lime
1145–47	Oil sand

Humble O. & R. Co.'s Ellis A-3, Sec. 2, T. 14 S., R. 21 W.

1150–52	Sandy shale
1152–53	Rock
1153–55	Gas sand
1155–56	Rock
1156–63	Sand

Smitherman & McDonald's E. E. Womack No. 3, Sec. 10, T. 14 S., R. 21 W.

1140–97	Gumbo
1197–98	Cap rock
1198–1208	Oil sand
1208–9	Cap
1209–11	Oil sand
1211–60	Missing
1260–1330	Hard sand and lime rock
1330–1400	Hard sand and streaks of lime
1400–1510	Shale and gumbo

From these records we see that the Nacatoch as drilled consists in general of two sands broken by a few feet of shale or hard cap. In the highest parts of the field the first sand, which is about 25 feet thick, contains the gas. On the flanks of the structure, the gas in this sand is gradually replaced by oil until the whole productive thickness is oil sand. A few wells near the top of the structure have penetrated the second sand a few feet, but very little oil has been found. In fact this sand appears to carry considerable water. In completing wells at Irma it is usually good practice to drill into the sand not more than 20 feet even on the highest parts of the structure, lest this lower sand be touched and its water be mingled with the oil or gas from the upper sand.

The general water level for the field is about 880 feet below sea; consequently wells on the flanks of the structure should penetrate the sand only until this subsea depth is reached if a commercial well is desired. However, practically all the wells that have been producing for some months are making considerable water. This water is generally not sufficient seriously to endanger the production.

Character and Origin of the Oil at Irma

TABLE V

Analysis of Irma Crude*

Gravity	14.7° API.
Water	5 per cent

DRY CRUDE DISTILLATION

Percentage	Degrees Bé.
5	28.8
10	27.0
20	25.5
30	27.6
80	18.3
Total	80 per cent gravity, 26.6° Bé.
Coke and loss	20.7 per cent

Taking the 80 per cent distillate and re-running all percentages based on the original charge:

Percentage	Degrees Bé.
5	48.4
10	48.4–44.8
15	36.3
20	32.3
25	32.6–30.2
35	27.6
45	25.0
80	18.3

SUMMARY

Percentage		Degrees Bé.
Kerosene	10	44.8
Gas oil	15	32.6
Light lube	20	26.7 (Viscosity at 100°–58 sec.)
Lube oil	35	18.3 (Viscosity at 100°–260 sec.)

Flash	390° F.
Fire	450° F.
C.T.	37° F. (paraffin)
Coke and loss	20 per cent
Coke by weight	20.7 per cent

* Humble Oil and Refining Company laboratory, Baytown, Texas.

The oil somewhat resembles the Gulf Coast "Grade A" oil, and similarly is desirable for making lubricants.

Whether the oil at Irma is indigenous to the Nacatoch or has progressed up the fault plane from sands or formations below is an open question and one that it is dangerous to speculate upon too much. If some lower bed is the source of the oil we should expect to find at least showings in some of the lower sands, but down to 3,000 feet within a quarter of a mile of the fault in the Nacatoch not even showings have been found at Irma. The Saratoga and Annona chalks, whose bituminous content may be much higher than their light color suggests, would be a convenient source of the oil. The black Midway shales, however, due to faulting, offset the Nacatoch sand and would be a still more convenient source of the oil. If we assume that the oil came from some lower source it is difficult to understand why enough salt water did not come up with it to increase greatly the sodium chloride content of the Nacatoch water.

Water Accompanying the Oil

The water with the oil at Irma is not a salt water, but rather a brackish water. Owing to the fact that the field lies only 25 miles down the dip from the exposure of the producing Nacatoch sand, the meteoric waters have been able to travel so far south from the intake, thus diluting the original salt water. This would indicate that dilution occurred prior to the period of maximum faulting, else the faults would have barred the water from the south side of the graben.

The character of the Nacatoch water at Irma cannot plausibly be explained by infiltration down the fault plane either from the surface or from sands in the Wilcox on the low side of the fault, on account of the pressure such waters must overcome to get into the Nacatoch. At Falcon, 10 miles southwest of Irma, wells that tested the Nacatoch in the graben

found very salty water. This can be explained by vertical migration of salt water along the fault plane from the Buckrange sand. That this Buckrange water did not advance high enough to contaminate the Nacatoch water may be explained by the thick, impervious Midway shales faulted against the Nacatoch sand which could serve as a barrier to further upward migration of the water.

TABLE VI

ANALYSIS OF WATER ACCOMPANYING THE OIL AT IRMA*

HUMBLE OIL AND REFINING COMPANY'S GROVE A-3, SEC. 2, T. 14 S., R. 21 W.

Chlorine	5,760 parts per million
Sulphur trioxide	144 parts per million

ANALYSIS OF WATER FROM WILCOX SAND WATER WELL 200 FEET DEEP ON HUMBLE OIL AND REFINING COMPANY'S GROVE-A LEASE

Chlorine	1,460 parts per million
Sulphur trioxide	None

* Barrow-Agee Laboratories, Shreveport, Louisiana.

DEEP SAND POSSIBILITIES

As yet no deeper sand at Irma has shown oil. Only the two deep wells have been drilled: Smitherman & McDonald's Waters No. 2, Sec. 10, T. 14 S., R. 21 W., which cut the fault near the west end of the field and went to 2,320 feet (Tokio formation), and Smitherman & McDonald's E. E. Womack No. 3, in Sec. 10, T. 14 S., R. 21 W., ¼ mile back from the fault, which was probably about 400 feet in the Trinity formation at 3,000 feet, its total depth. The Magnolia's Johnson No. 1 in Sec. 3, T. 15 S., R. 21 W., 4 miles south of the Irma field, went to 4,600 feet and had no showings in the deeper sands, although it penetrated more than 1,700 feet of the Trinity. In this well the pisolitic zone which probably occurs near the base of the anhydrite in the Trinity section in Caddo Parish, Louisiana, occurs at 3,420 feet. At Falcon, Sec. 9, T. 15 S., R. 22 W., 10 miles southwest of Irma, the Humble Oil and Refining Company's Bodcaw Fee No. 4-A encountered the top of the Trinity at 2,535 feet and the pisolitic zone at 3,022 feet. No authentic showings in the Trinity were found in this well. The possibilities for deep oil in the Woodbine or Trinity at the east end of the Irma fault where the anticline has widened seem more attractive. The two deep wells drilled at Irma were 2¼ miles southwest of this favorable area. It is hoped that a deep well will ultimately be drilled here.

Production

On September 1, 1927, the field had sixty-five wells producing 2,600 barrels of oil. There are also five gas wells with a rock pressure of 300 pounds, the original pressure having been 750 pounds. The productive area on this date involved 475 acres, from which an estimated total of 1,878,478 barrels of oil have been produced, giving an acre yield of 4,000 barrels. The oil is generally run into open pits as produced; there-

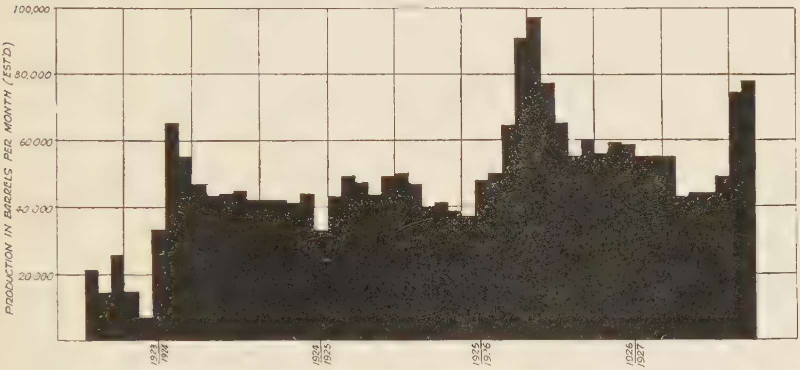


FIG. 4.—Monthly production of the Irma field since August, 1923.

FIG. 5.—Decline curve for the average well at Irma.

fore, day-to-day production gauges are lacking. Consequently the monthly oil shipments (Fig. 4) must be used in preparing future production curves.

The Keystone-Waters lease in Sections 10 and 11, 60 acres of which may be regarded as producing, and on which the discovery well was drilled, has produced to September 1, 1927, approximately 9,000 barrels to the acre.

Estimates made on the rate of the decline of the field as a whole (see curve, Fig. 5) indicate that an ultimate yield of 7,500 barrels to the acre may be expected for the field.

Production Methods

Drilling the 1,200-foot wells with a rotary outfit is a simple matter at Irma, but the heavy, viscous oil, and the great quantities of soft sand the water later brings in, give the producer much trouble. Cups cut out quickly after water comes into the well, and the liners become clogged with sand every few days. The general practice is to set $4\frac{1}{2}$-inch perforated liner opposite both the gas sand and the oil sand. After the first year or so, frequent cleaning-out so reduces the sand that not nearly so much trouble is experienced with old wells as with the new. In pumping, the regular Axelson barrels are in general use, although some have tried the fluid packed pumps. These are not so satisfactory on account of the great amount of sand wearing them out quickly.

The oil flows or is pumped into open pits, from which it is picked up and passed through cooking vats. If Tret-O-Lite is added to the vats the bottom settling can be separated at a lower temperature, and the resulting treated oil is of higher gravity than if heat only is used. One operator uses a still for treating. This consists of a large brick furnace with coils through which the oil runs. Later the oil goes through cooking vats. Most operators pass their oil through a Ferris separator consisting of a joint of 10-inch pipe with 2-inch coils. Excelsior has not been found effective in separating water in this oil.

As no pipe line serves the field, the oil is first heated, if necessary, to about 100°, and then pumped to loading racks for shipment in tank cars equipped with heating coils, over the Reeder Railroad to the Missouri Pacific Railroad.

The practice now is to core into the sand and set casing on the cap, since it has been proved that no water exists above the sand or cap. The cap ranges from 1 to 5 feet in thickness, and in some places is missing. The underlying oil sand is soft for 15 feet or more. Wells drilled deep into the sand find it broken below with hard caps and soft streaks of sand. The gas appears to be coming from the top of the same sand as the oil, although structurally higher.

The wells cost about $4,500.00 to drill and from $5,000.00 to $10,000.-00 to standardize, depending on the character of the equipment. The Humble Oil and Refining Company has several Lufkin pumping units in use which are operated by electricity and have proved satisfactory provided the current is supplied steadily.

IRMA FIELD STATISTICS

	Barrels
Estimated daily production (September 1, 1927)	2,600
Average daily production per well	40
Oil in earthen storage	137,600
Oil in steel storage	129,772
Total oil in storage	267,372
Total tank car shipments to September 1, 1927	1,279,106
Oil shipped and in storage (estimated)	1,546,478
Oil used for fuel	332,000
Total oil produced to September 1, 1927	1,878,478
Completed oil wells	87
Producing wells	65
Shut down, cleaning out, etc.	19
Gas wells	6
Abandoned wells	36
Drilling wells	4
Wells waiting on standardization	2
Total wells drilled	135

NOTES ON THE McKITTRICK, CALIFORNIA, OIL FIELD[1]

WALTER A. ENGLISH[2]
Los Angeles, California

ABSTRACT

In 1910 Arnold and Johnson published a report on this field, showing a low-angle overthrust fault as the controlling structural feature. Their description has been widely quoted in subsequent literature, and this structure will continue to be referred to as one of the few oil-bearing structures of that type. It therefore seems desirable to have some fresh word on the subject, and particularly whether the last twenty years have brought forth facts which make the original description inaccurate or misleading. Detailed areal mapping by the writer indicates that there is a low-angle overthrust fault present, but that it is complicated by many minor thrusts, and by a series of steep hade strike faults. The latter, rather than the overthrust, determine the position and structural relationship of the productive sand bodies, though the overthrust shale does at some places form a roof over the productive sands.

INTRODUCTION

In 1910 Arnold and Johnson published *U. S. Geological Survey Bulletin No. 406*, in which the McKittrick as well as other fields of the Sunset-Midway region were described in detail. Since that time there has been practically nothing published on the geology of the McKittrick field, other than a small paper by Clark Gester, calling attention to the significance of the presence of a small area of outcrop of Etchegoin formation a short distance south of the field. At the time that Arnold and Johnson published their report, the McKittrick field was well past its peak, and there has been little incentive to further study of the very complex structure that is present within this area. Geologists for the Associated Oil Company, which holds the greater part of the productive land, have made some subsurface studies, and the writer and others have mapped the surface in more or less detail. The general result of such studies is that a few empirical rules governing the productive limits and the presence of bottom and edge water have been developed, but little has been added to our knowledge of conditions controlling oil accumulation. The main feature of structure (overthrust fault) described by Arnold and Johnson still stands as correct, and the details of structure are so com-

[1] Presented before the Association at the Tulsa meeting, March 26, 1927. Reprinted from *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 6 (June, 1927), pp. 617–20.

[2] Continental Air Map Company.

plicated that, while they may not have been correctly determined by Arnold and Johnson, later workers are not able to substitute anything much more definite.

The structure sections by Arnold and Johnson (their Figure 6 and Plate V) showing infolding and overturned anticlines give an entirely erroneous idea of the controlling structure.

STRATIGRAPHY

For those not immediately familiar with California stratigraphy, the following is a brief description of the formations important with relation to oil in this part of San Joaquin Valley.

Maricopa shale (Miocene).—Marine brown siliceous shale with diatoms, equivalent to Monterey and Salinas shale of other areas. Maximum thickness about 10,000 feet. The upper few thousand feet are softer shale, layers of soft white sandstone, and granitic boulder beds, known as the Santa Margarita phase of the Maricopa shale. The upper phase yields oil in the Sunset-Midway field.

Etchegoin formation (lower Pliocene).—Marine sands and clays with plentiful sea shells. Rests unconformably on the Santa Margarita and older formations, though the break between it and the Santa Margarita is not always prominent. Most of the oil of the Sunset-Midway field comes from this formation.

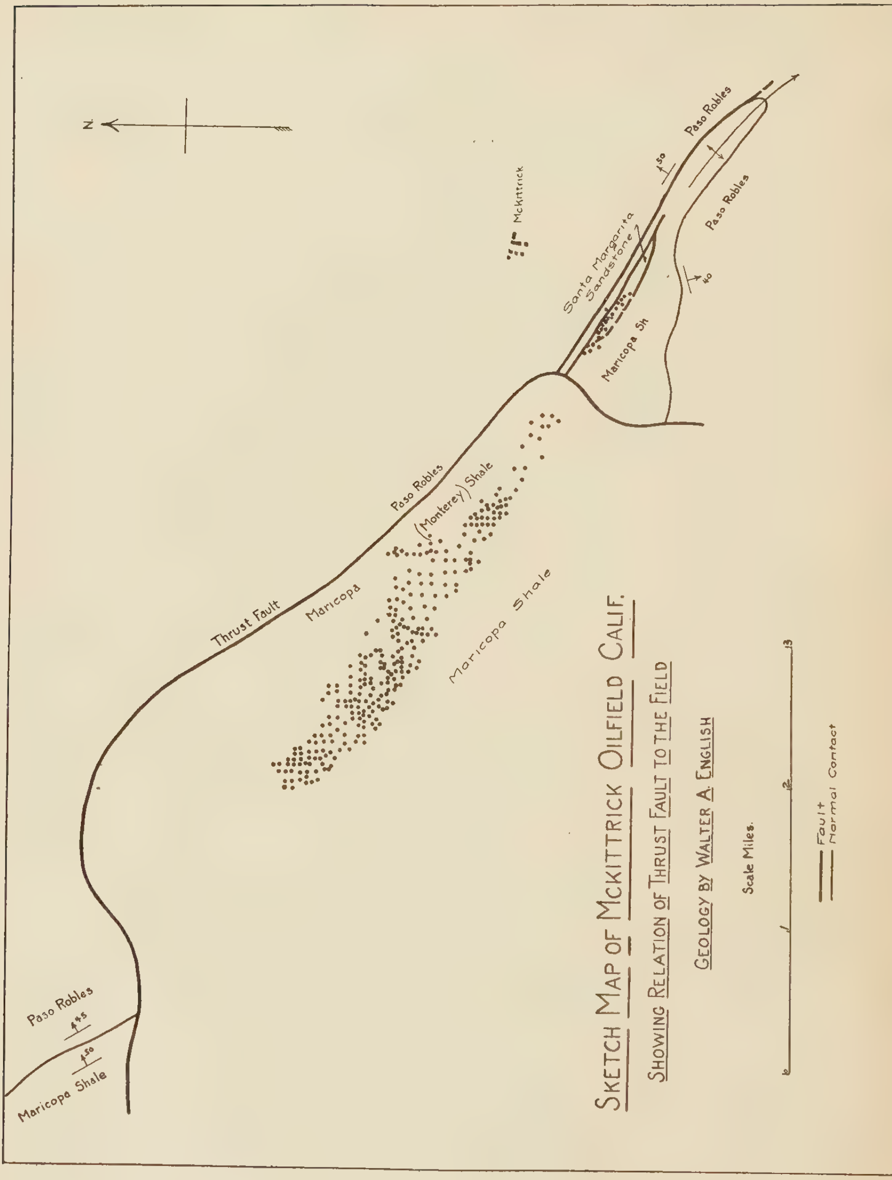
Paso Robles formation (upper Pliocene).—This formation is made up of marine- and fresh-water clays and sands, and is markedly unconformable on the Etchegoin and all older formations. Basal beds yield considerable oil where they overlie the Etchegoin or Santa Margarita, but not elsewhere.

STRUCTURE

All formations are steeply folded and faulted, the chief period of deformation being of post-Paso Robles age.

The most prominent structural feature of the McKittrick field is an irregular overthrust fault, which obscures the significant structure with regard to oil accumulation in most of the field. The productive area is about 4 miles long and from a few hundred feet to about half a mile wide. Except at the extreme south end of the field the wells pass through the Maricopa shale, and obtain oil from the underlying Etchegoin formation. The latter is identified by sea shells which have been obtained from the drill cuttings.

The Maricopa shale on the surface of the overthrust area dips steeply and irregularly, and is much contorted, brecciated, and silicified. There


Sketch Map of McKittrick Oilfield Calif.
Showing Relation of Thrust Fault to the Field
Geology by Walter A. English
Scale Miles.
Fault
Normal Contact
N
McKittrick
Paso Robles
Santa Margarita Sandstone
Maricopa Sh
Paso Robles
Thrust Fault
Maricopa
(Monterey) Shale
Maricopa Shale
Paso Robles
Maricopa Shale

are many vein tufa deposits, formed by superficial migration of water along planes of minor faulting. Irregular inliers of Paso Robles and Santa Margarita formations are folded and faulted into the Maricopa shale. Most of the lesser faults are of the steep hade type, and some of them belong to a period of faulting subsequent to that of the main thrust. Many secondary thrust faults of fairly low hade may be seen, but the main fault is not well exposed except at the north end, where it bends around toward the west.

The presence of the steep hade faults is important in relation to the producing structure. The fact that the central part of the field follows a strike valley, along the sides of which vein tufa is exceptionally plentiful, suggests that the faults determining this valley have also had an effect on the position of the productive sands.

At the extreme south end of the field, a small productive area is left uncovered by the overthrust. Here the oil comes from nearly vertical beds of Santa Margarita sandstone, which form a faulted inlier in the Maricopa shale. Distinct oil seeps and tar sands are found along the faults which bound the inlier, and mammal bone deposits similar to those of Rancho La Brea have been found in this locality.

Farther north, the irregular outline of the productive area indicates that the structure just described does not extend any great distance northwest beneath the overthrust shale. The structural control determining the area of oil occurrence in the central and northern part of the field will probably never be determined accurately, as the only available data are those furnished by old well logs, most of which are not very satisfactory for correlation purposes.

In the writer's view, the structure, and the stratigraphic conditions beneath the thrust plane, and not the presence of the thrust fault, are the controlling features which determine the presence of the productive area. We have already seen that the production is not limited southeast by the area of overthrust shale. On the northwest the field ends where the overthrust shale extends a maximum distance northeast. If the overthrust were the determining feature we should expect the field to be at its best at the point where it ends. In some parts of the field the productive sands are immediately beneath the thrust plane, and here the shale may serve as an impervious capping. At other places the oil is obtained several hundred feet deeper than the lowest Maricopa shale encountered in the wells.

About a mile northwest of the end of the field, and approximately in line with its trend, a normal contact of steeply-dipping Maricopa shale

and Paso Robles formation emerges from beneath the thrust plane. The absence of evidence of oil here is accounted for by the writer by the absence of the Santa Margarita and Etchegoin formations at this point.

The only interpretation of surface structure in this field, of which the writer is aware, other than that of an overthrust, is that of J. A. Taff, of the Southern Pacific. He believes that the overriding of younger formations by the Maricopa shale is of a superficial character, and should properly be considered an extensive landslide rather than a thrust fault.

In most references to this field, the thrust fault is considered to be the controlling feature determining the presence of the oil field. This is an error, as the overthrust shale in only a few places forms the roof over the oil-bearing beds, and in most of the area the thrust block simply serves to obscure the significant structure. Due to the fact that the significant structure in this field will always be subject to considerable doubt, the writer would suggest that it is unwise to use this field as an example of oil occurrence under conditions of overthrust faulting.

TRI-COUNTY OIL FIELD OF SOUTHWESTERN INDIANA[1]

R. E. ESAREY[2]
Bloomington, Indiana

ABSTRACT

The field is located at the juncture of Pike, Gibson, and Warrick counties, Indiana, where the surface formations are of Pennsylvanian age. The regional dip amounts to 35 feet per mile to the southwest, and the collecting structures are mere pimples upon the regional slope. Surface structure does not coincide with subsurface dips, the limestone outcropping in the field showing production coming from a syncline. The oil sand manifests evidences of lens-like accumulation and may be responsible for the arching of the overlying rocks.

The Oakland City sand or the Mooretown sandstone forms the reservoir for petroleum. Gas is entirely lacking; each well had to be shot and put on a pump to secure production. Water is almost a negligible quantity, and the amount handled with the oil is decreasing. The crude is of good quality, green to brown in color, and fairly high in gasoline content. Production is light; consequently development has been slow.

INTRODUCTION

The area under consideration is typical, in size and extent, of the oil fields of this region. A previous knowledge of conditions and the availability of first-hand information made its selection desirable. The writer takes this opportunity to express his appreciation of the assistance rendered by W. W. Rogers and J. O. Rosebaum, of the Consolidated Oil Development Company. W. N. Logan also deserves much credit for aid in the interpretation of data, especially the correlation of well logs.

HISTORY

The Tri-County oil field is one of several small producing areas in Pike and Gibson counties in southwestern Indiana, and is a fairly typical example of the group. The field is located where Pike, Gibson, and Warrick counties join, in Sections 7, 8, 9, 15, 16 and 17, R. 8 W., T. 3 S. (Fig. 1).

It was strictly a wildcat proposition when drilling started. Two brothers, both drillers, leased the land and commenced drilling the first well. They subsequently entered into partnership with the Consolidated

[1] Presented before the Association at the Tulsa meeting, March 26, 1927. Reprinted from *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 6 (June, 1927), pp. 601–10.

[2] Indiana University. Introduced by Sidney Powers.

Oil Development Company, providing for operations to continue on about an equal basis. No geological advice was sought or utilized in locating the first few wells, nor were surface indications favorable.

FIG. 1.—Spot map showing location of Tri-County oil field in Indiana.

The first location was on the Yaeger farm in Section 9, at a rather high surface elevation. Only a slight showing of oil was obtained in the "brown sand" when the well was completed in August, 1924. An extraordinary amount of gas was encountered in the higher formations underneath a coal bed, probably Coal IV, according to the system of numbering in Indiana.

The second well drilled, No. 1, on the Raeburn lease, gave the first commercial production. It came in at 15 barrels a day during November of the same year. The Ohio Oil Company secured leases upon the northwest quarter of Section 16 and drilled five wells altogether, one of which made 75 barrels the first day. Gradual development has ensued, in keeping with the light production of the field.

PHYSIOGRAPHY

The field lies a few miles within the western edge of the driftless area of Indiana, so that the surface has not been altered by glaciation. The term "gently rolling" adequately describes the region, and the fact that it is included in Fenneman's physiographic division, "The Aggraded Valley Section," shows the nature of the drainage. Most of the bed rock is soft Pennsylvanian shale or sandstone which has offered little resistance to erosional degradation. As a result a homogeneous plain has been formed parallel to Wabash River more or less regardless of glaciation. The relief is generally moderate and gentle, but in many places the uplands rise abruptly from the wide, level stream valleys. A few notable examples occur where isolated hills of bed rock, some of which are more than 100 feet in height, stand out prominently with respect to the sur-

rounding alluvial or glacial plain. Few places exceed 700 feet in elevation, and the general level is near 500 feet.[1]

STRATIGRAPHY

All of the exposed formations in this district are of Pennsylvanian age, either Alleghenian or post-Alleghenian. Most of the rocks are shales and sandstones, interbedded with a few limestones and coal beds. Coal V (of Indiana) crops out a few miles east, and numbers VI and VII appear south and west of the oil field. Two or three limestones of local extent occur in this part of Indiana, only one of which has been important enough to be named and mapped. One such limestone is exposed within the Tri-County field and has been used as a datum plane for surface mapping. Where typically developed it occurs in two beds separated by 5 to 10 feet of shale. Both strata range from 5 to 10 feet in thickness and assume a reddish-brown color where weathered.

The Somerville or West Franklin limestone is stratigraphically about 60 feet above the first-mentioned limestone, but is very similar in appearance. It constitutes the most reliable datum plane for surface mapping for many miles on the southwest, because of its plentiful outcrops.

Coal V of the Petersburg group crops out a few miles east of the field and can be used as a horizon for structural control. For such indications, it is probably the most reliable of any of the coal beds in the state. Most of the collecting structures found in Dubois and Pike counties have been defined upon this stratum. Almost every section in each county has been tested for coal, and these drilling records constitute the chief source of information as to the depth and thickness of Coal V. No coal bed is reliable as a basis for determining subsurface structural conditions, but as in many places the irregularities of this one are depicted in a general way on the formations beneath, it is widely used in southern Indiana.

An erosional unconformity exists between the Pennsylvanian and the Mississippian in Indiana, causing the Mansfield sandstone, the basal member of the Pennsylvanian, to overlap many of the Chester formations and even rocks as old as the Devonian. Where the Mansfield is absent, depressions in the eroded surface of the Mississippian are occupied by shales. In most places the Mansfield carries water under pressure and ordinarily completely fills wells drilled into it. Typically it is a massive, poorly cemented sandstone, of sufficient porosity to contain much water. It ranges in thickness from 50 to 300 feet. Conglomeratic phases com-

[1] C. A. Malott, "Physiography of Indiana," *Indiana Handbook of Geology*, 1922.

monly comprise the lower part, the size of the grains decreasing in the upper parts.

The Chester of the Mississippian is represented in Indiana by a series of clastics containing a few outstanding limestones. Only a few horizons are conspicuous or persistent in well records, and these occur in the lower group of the Chester. The upper Chester is principally shale and exhibits no marked uniformity of characteristics, though a few units may be identified in the middle part. The following are the more important.

The Tar Springs sandstone may be identified in places and occurs at some points directly under the Mansfield sandstone. Except for the Golconda limestone and possibly the Cypress sandstone, it is the only recognizable unit of the upper and middle Chester. Typically it is fine-grained, massively bedded, and poorly cemented. In many well logs its contact with the superjacent Mansfield is not clearly defined. As a water-bearing horizon it ranks second only to the Mansfield.

The Beech Creek limestone of the lower Chester, called the "Little lime" by drillers, is used for correlation purposes. It is normally 15 or 20 feet thick near its outcrop, but thickens to 40 feet in places, according to well records. The Beech Creek contains few partings and is characteristically overlain by the Cypress sandstone.

At greater depths, a stratum called by drillers "red rock" is used as a marker. It probably correlates with the Reelsville limestone in the lower Chester. Characteristically it is reddish-brown in color and 3 to 5 feet in thickness, but it may change into shale or become so thin as to be passed unrecognized. A short distance below the Reelsville horizon a massive limestone is encountered which represents the Beaver Bend formation. Where it crops out on the east, its thickness is normally about 15 feet, but well records reveal 40 to 50 feet of it. It is gray in color and rarely absent, and, coming just above the Mooretown sandstone, forms a satisfactory datum plane for subsurface structural determinations.[1] Figure 2 shows a general section for the field, with the approximate depths of the formations.

Throughout the field, only the Oakland City sand is productive. It correlates with or comprises a part of the Mooretown sandstone of the general section. Another sand, called the Brown sand, is reached a short distance below the Oakland City horizon. The Brown sand is more commonly a dolomite or porous limestone than a true sandstone, and is

[1] C. A. Malott, "The Upper Chester of Indiana," *Proc. Indiana Acad. Sci.*, 1925.

W. N. Logan, "Geological Conditions in the Oil Fields of Southwestern Indiana," *Indiana State Dept. Cons., Div. Geology*, 1924.

contained within the Paoli formation of the geologic column. Excellent showings have been found in the latter sand, but there is no commercial production to date in this field.

GENERAL STRUCTURAL CONDITIONS

The Eastern Interior coal basin into which the rocks dip from the Cincinnati arch forms the major structural feature of southwestern Indiana. The basin includes south-central Illinois, northwestern Kentucky, and southwestern Indiana. The regional dip in southern Indiana is determined by the extension of the formations from the Cincinnati uplift and its flanks into the coal basin. The inclination of the rocks is gentle or lacking near the crest of the arch in eastern Indiana and increases in gradient toward the basin. The belts of outcrop of the formations in the southern part of the state extend generally north and south, as the arch has been truncated, exposing the edges of the successive formations. The region under consideration lies in the most westerly of these belts, on the east slope of the coal basin, where the rocks dip toward the west at the rate of 35 feet per mile. The surface formations are of Pennsylvanian age, consisting of sandstones, shales, and thin limestones intercalated with beds of coal. The type of topography formed by these non-resistant rocks has been described.

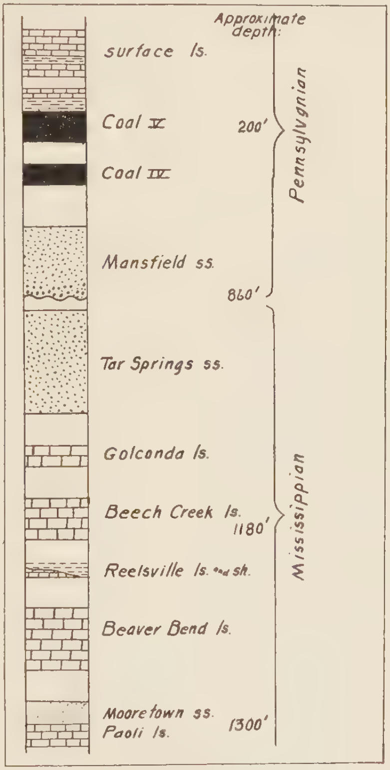


FIG. 2.—Generalized section of the Pennsylvanian and upper Mississippian in the Tri-County field, showing the more easily recognizable horizons. Thicknesses of formations greatly exaggerated. Approximate depth in feet.

The local areal geology is complicated and not thoroughly worked out. Thin limestones and coal beds, local in extent and interbedded with shales and sandstones of irregular thickness, make correlation difficult without intensive study. Cross-bedding exists within the sandstones, and

likewise variations in thickness and changes of facies occur within short distances. Consequently surface mapping to determine structural conditions, especially where correlations are involved, is hazardous. Surface and subsurface structures conform to each other only in a general way.

Where a coal bed is used for a datum plane, in many places the higher levels between local coal basins may be depicted on a structural map without any actual structural deformation existing. Very promising structures outlined on coal beds have been accounted for by abnormal thicknesses of

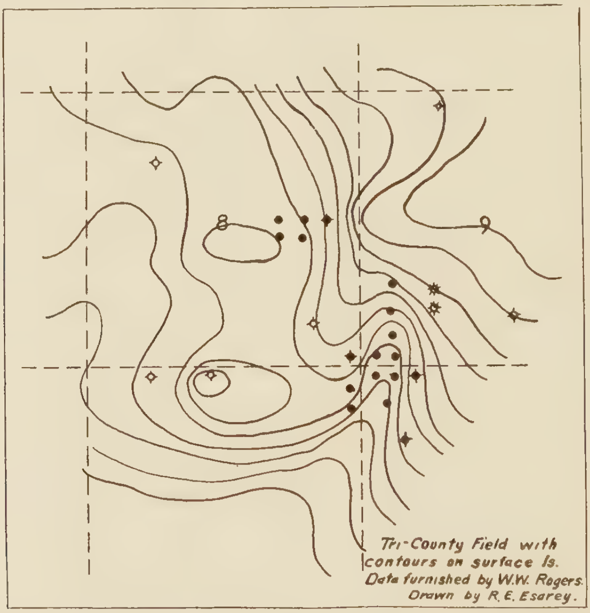


FIG. 3.—Contour interval, 5 feet. Width of area mapped about 2 miles. Notice producing wells located in a syncline. Compare with Figure 4.

sandstone under the coal. In places the thickness of the coal bed will help determine the presence of coal basins or actual structure. In addition to the Somerville or West Franklin limestone there are other limestones of limited extent which may be used for surface mapping. One of these extends through the Tri-County field. The accompanying map shows the discrepancies between surface and subsurface mapping in this field. (Fig. 3. Compare with Figure 4, where the contours are drawn upon the oil sand.)

The Somerville occurs in two beds separated by shale which may locally thin and thicken. The beds convergë to form one bed near Ohio

River, and at some points the upper bed has been removed by erosion. Care must be exercised in choosing the same bed for a datum plane and in noting the shale interval. It seems probable that a limestone deposited upon a shale or above a coal bed would settle with the underlying formation or even compress the shale or coal in such a manner as to indicate pronounced dips where none occurs. The surface limestone in the Tri-

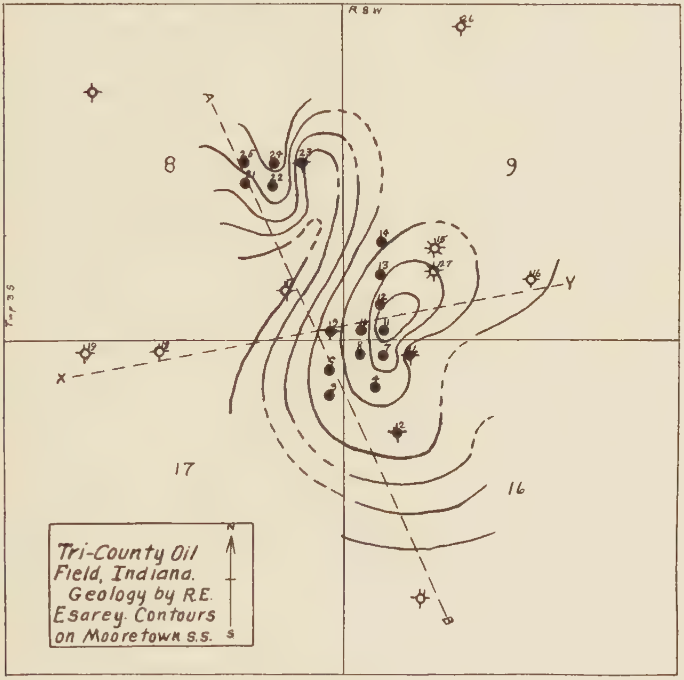


FIG. 4.—Contour lines drawn upon the top of the Oakland City sand or the Mooretown. Interval, 5 feet. Notice location of producing wells on structure. Width of area mapped, 2 miles.

County field fulfills these conditions by evincing structure which does not "hold up" on the lower formation.

The predominating type of fold in this part of Indiana is the small anticline. Terraces or monoclinal structures are also common, but are possibly depositional features rather than structural.

Most terraces and anticlines so far discovered have been small in size, amounting to mere pimples on the regional slopes. Productive areas upon these structures range from a few acres in size to 160 acres, supporting

from 3 to 40 wells. In some fields many small anticlines are grouped together, that is, a succession of folds occurs, separated by synclines or narrow, non-productive belts, making the aggregate producing area fairly extensive.

RELATION OF ACCUMULATION TO STRUCTURE

In most of the fields throughout southwestern Indiana the major part of the oil accumulates in the southwestern part of the collecting structure. The direction of the regional dip would tend to make this a normal condition. Gas is generally present near the crest of the anticlines with the oil on the flanks.

Only small amounts of gas were encountered in the Tri-County field, not enough in all the wells to furnish power for the pumping stations. Wells No. 15 and No. 27 produced small volumes of gas when brought in, but no constant flow occurred, nor was the volume large enough to build up a measurable pressure. The total absence of gas seems exceptional, as near-by fields have produced it in large quantities. The drillers report from 5 to 20 feet of dark shale everywhere overlying the oil sand, thus preventing the easy escape of gas from the structure, if any has ever been present. Crude from the field has a Bé. gravity of about 34°, a brownish-green color, and, from its odor, seems to be a live, fresh oil. However, none of the wells was free-flowing or exhibited evidence of gas pressure. Even ordinary water pressure is lacking, so that the gas, if originally present, might have escaped up the regional dip. The anticline is small and may not have afforded a sufficient trap to collect and retain gas in measurable quantities. A few miles on the west, near Somerville, Indiana, is a fairly large anticline which has been found to contain millions of cubic feet of gas, but no oil in commercial quantities. The gas collecting in such a quantity may have completely or almost completely filled the structure and forced the migration of oil up the regional dip toward the field under discussion. The small size of the anticline in the Tri-County field remains the most potent factor in explaining the absence of gas, however.

Oil production has occurred on the top part as well as the south and west parts, since gas is not present. The largest well, No. 8 (Fig. 4), was brought in by the Ohio Oil Company with an initial production of about 75 barrels per day. Well No. 10, an offset one location north of the foregoing well, started at 50 barrels per day. Offset wells east of each of these produced similar amounts, when first pumped. As the farthest north well in the pool came in at 10 barrels, the limit of production in this direction has not been definitely determined. On the extreme southwestern edge of the field the wells had low initial production, but are profitable to

operate. The amount of water pumped with the oil is greatest in these latter wells.

A second collecting structure, seemingly a terrace, furnishes production for the northern part of the field. Only four producing wells have been drilled upon it, so that to date its exact nature has not been revealed. Figure 3 shows the trend of surface structure, however. Additional wells are being started which will test the productive limits of this reservoir.

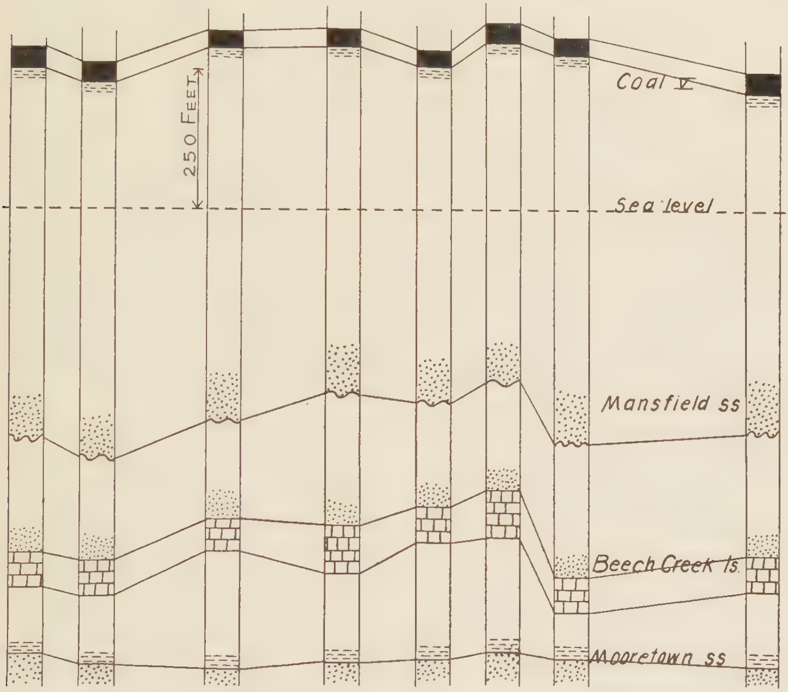


Fig. 5.—Cross section along the line *A–B* in Figure 4.

Water conditions are abnormal in that very little water is present; certainly not enough to interfere with drilling or production. No wells brought in had heavy gas or water pressure. Most of them filled up with water and oil for only a few hundred feet after shooting. The column of fluid is easily pumped down and does not refill the casing rapidly. According to the field superintendent in charge, the amount of water handled since the wells came in has materially decreased. Evidently underground water circulation is obstructed, or very meager, throughout the sand.

Figures 5 and 6 are cross sections of the collecting structure along the dotted lines in Figure 4. The first is along the strike, *A* to *B*, and the other extends parallel to the direction of dip, *X* to *Y*. In Figure 5, the Beech Creek limestone shows a more pronounced folding than other

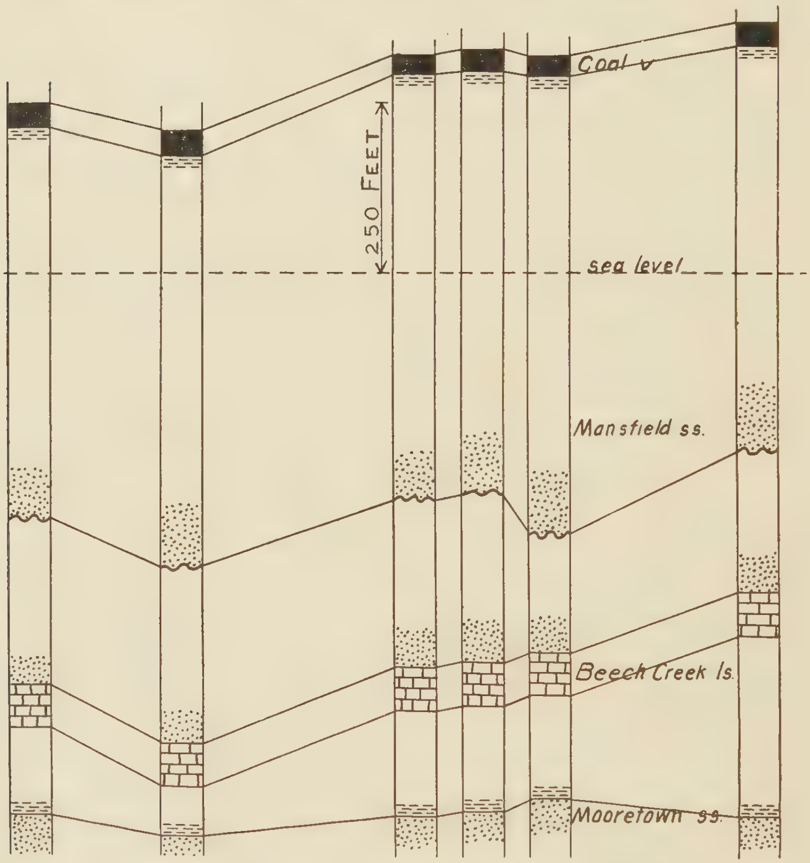


FIG. 6.—Section along line *X–Y* in Figure 4.

horizons, but in other respects is similar to Figure 4. Coal V indicates a decided syncline in the center of the field which no other stratum follows. The writer believes that most of the irregularities and variations in the cross sections are due to differences in thickness of the formations or intervals—depositional rather than dynamic. The correlations are the best possible under the conditions, as a few of the records were poorly

kept. Figure 6 reveals only a monoclinal structure on the Beech Creek limestone and a very slight reversal on Coal V. The oil sand shows the greatest east dip, which suggests accumulation in a lens of sandstone.

RESERVOIR ROCKS

The Oakland City oil horizon or the Mooretown sandstone averages about 20 feet in thickness throughout this field. Where not affected by oil, it is white or gray in color, which, with its hardness and fineness of grain, makes it appear similar to a limestone. The productive part of the sand begins about two feet "in" and extends nearly to the base. No particular stratum is more highly saturated than another, the samples indicating a uniform vertical distribution of oil. Few wells have continued through the sand, as the lower few feet are seldom productive and water is commonly present in the limestone beneath. Shooting is essential to production.

The thickness of the sand is different in different wells, and the oil content varies with the porosity of the sand, and the porosity with the thickness. For example, in well No. 24, 26 feet of porous well-saturated sand are found, while in well No. 23, only 600 feet away, the sand is only 7 feet thick and is replaced largely by shale, in addition to being finer-grained and better cemented. At other places, especially down the dip of the structure, wells have struck thin beds of sand, with shale occupying the remainder of the normal interval. No. 6 has only 9 feet of producing sand, which is overlain by "shelly" sandstone grading rapidly into true limestone. Well No. 7, just west of No. 6, has 21 feet of saturated sand and is one of the best producers in the pool. Again, No. 17 passed through only 11 feet of sand, which is below normal. Complete records of the thickness and samples of the sand are not available, so that a cross section or study of conditions is not possible, but the foregoing illustrations point to a lens-like accumulation of sand forming the oil reservoir.

The uppermost two feet of the Mooretown is not productive as a rule, or even saturated with oil. The bulk of this stratum is fine sand intermixed with some shale and pyrite particles. The grains are mostly transparent quartz, uniformly small and subangular to well rounded. A small amount of calcium carbonate is present, which acts as a cementing agent. The absence of iron oxide is conspicuous, and the heavy metallic substances are not plentiful. The many particles and masses of pyrite merit discussion on account of their nature and abundance. The pyrite serves as a cementing substance for grains of sand and shale, but it likewise composes the major part of the masses. In size the concretion-like masses

range from $\frac{1}{32}$ inch to $\frac{3}{4}$ inch in diameter, but appear uniform in composition. In the larger masses the inclosed sand grains are well rounded and lend to the body as a whole the appearance of a well-cemented conglomerate. The number of masses and the amount of pyrite diminish with depth in the sand, according to available samples. However, the coloring imparted by the crude oil may obscure the pyrite.

Uncontaminated samples of water from the oil sand or the limestone beneath are not available at present. Its exact composition is therefore not known, but the chief mineral in solution is sodium chloride. The data point to the following explanation of the presence of iron sulphide within the sandstone. Ferrous sulphate in the water is reduced by sulphur bacteria, producing hydrogen sulphide. The latter, being a strong reducing agent, in turn precipitates the iron compounds in solution in the water as iron sulphides. Other explanations might appear with a more detailed knowledge of sand conditions.

The porosity of the Mooretown sand as a whole is very low for a "reservoir rock." Actual pore space is slightly under 5 per cent, as an average, from all samples collected, due to the irregular shape of the particles, the presence of some clay and calcium carbonate, and the fineness of grain. The character of the sediments indicates that deposition took place in relatively quiet waters away from the shore. Since the Mooretown overlies limestone and grades into it, this would certainly be true of the lower part. The central 20 feet is almost a pure sandstone, of greater porosity and coarser grain, thus more nearly approaching a shore or strand-line deposit. The production of oil comes almost exclusively from this part. The uppermost 3 feet again becomes fine-grained and well cemented with calcium carbonate. In addition, shale everywhere overlies the Mooretown, indicating that deep or quiet water conditions prevailed during the deposition of the upper part.

The character of the oil remains uniform throughout the field. Samples were taken from the different leases and each showed the same gravity, sulphur content, and fractionation percentages. The Baumé gravity is 34°, sulphur content less than 0.5 per cent, the gasoline fraction up to 150° C., 20.3 per cent, and the burning-oil fraction up to 275° C., 28 per cent. Production records for each well have not been kept and lease records do not show exact dates and amounts of new production added. Hence a graphic representation of production would be of little value.

FAIRPORT OIL FIELD, RUSSELL COUNTY, KANSAS[1]

THOMAS H. ALLAN[2] AND M. M. VALERIUS[3]
Russell, Kansas, and Tulsa, Oklahoma

ABSTRACT

The Fairport oil field, Russell County, Kansas, is at the northwestern edge of the Mid-Continent area. The prominent Cretaceous surface structure becomes stronger in the Permian and Pennsylvanian, and overlies uplifted crystalline rocks. The oil is at the top of the structure in a pool ½ mile wide by 4 miles long which has produced 3,500,000 barrels of 40° Bé. oil during the past three years.

By Thomas H. Allan

INTRODUCTION

The Fairport field (Fig. 1) was discovered in November, 1923, when the M. M. Valerius Oil & Gas Company drilled in the discovery well, Carrie Oswald No. 1. The block on which this well was drilled was leased by A. E. Seeley and J. E. Missimer on the instigation of J. H. Liggett because of the similarity of the topography and limestone outcrops to the Flint Hills of Greenwood County. They employed Cecil Welsh to make a geologic map. Later V. H. McNutt confirmed the mapping of Welsh and made a deal with M. M. Valerius to drill the block. The Valerius Oil & Gas Company was organized by the Wilcox Oil & Gas Company to do the drilling and was later bought out by the Wilcox Company.

The field is about 120 miles northwest of the Covert-Sellers field, which, at the time of discovery, was the farthest field toward the northwest in Kansas.

A description of the general geology of the region has been published by W. W. Rubey and N. W. Bass.[4]

GENERAL GEOLOGY

The plains of western Kansas dip gently east. The surface beds of Cretaceous age dip gently northeast. The Greenhorn limestone of the

[1] Presented before the Association at the Tulsa meeting, March 26, 1927. Manuscript received by the editor, January 16, 1928.

[2] Geologist, Midwest Exploration Company.

[3] Petroleum geologist, 101–2 Wilcox Building.

[4] "The Geology of Russell County, Kansas," *Geol. Survey Kansas Bull. 10*, 1925.

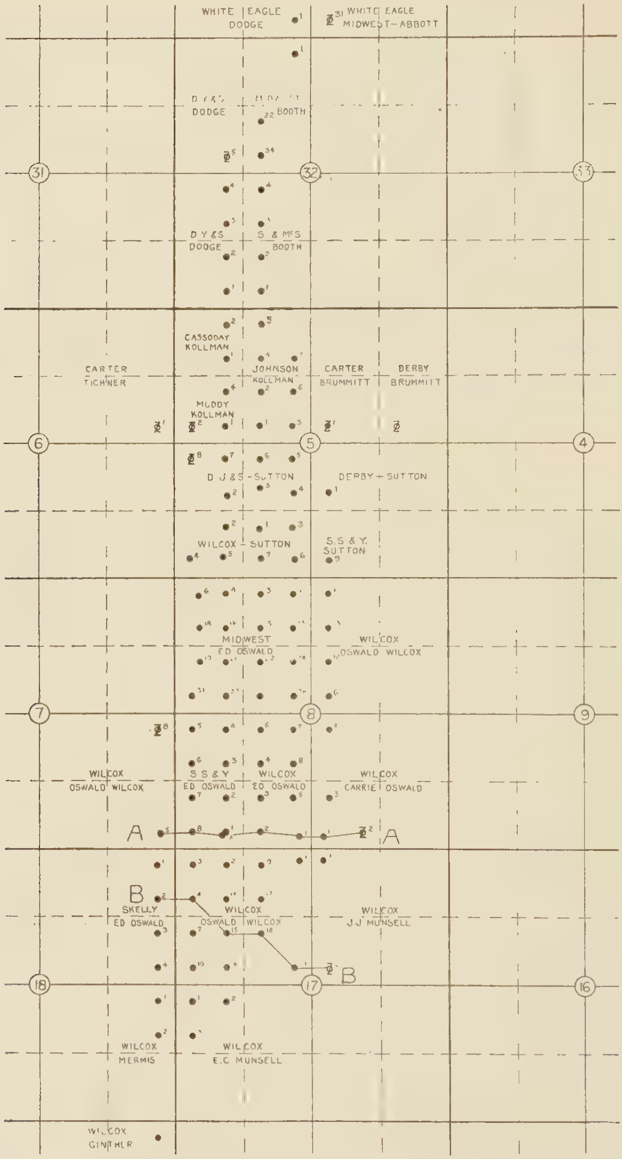


FIG. 1.—Map of Fairport oil field, Russell County, Kansas. Width of area mapped, 2 miles.

Benton formation makes a broad bench cut by the rivers and tributary drainage, giving excellent outcrop for the observation of surface structure.

STRATIGRAPHY

Figure 2 is a columnar section or composite log of the field. The Greenhorn limestone, composed of thin beds of chalky limestone, separated by blue shale, lies on the surface and makes excellent key beds for detail mapping. Below the Greenhorn is 25 feet of blue marine Graneros shale, the base of the Benton formation. The Dakota is predominantly sandy shale, red in color, and contains much iron. The sandstones are large cross-bedded lenses and contain very salty water. The underlying Comanchean is blue shale and white sandstone.

At a depth of 500 feet is a great angular unconformity. The Cretaceous above, with a regional northeast dip, lies on Permian Redbeds with a regional northwest dip. There is a 40-foot bed of anhydrite from 850 to 900 feet deep. A zone with a large quantity of salt extends from 1,200 to 1,500 feet in depth, below which are red rock, shale, anhydrite, and some dolomite to the base of the Permian at 2,100 feet. The upper part of the Pennsylvanian is blue shale with several thin limestones, with a sandy lime carrying gas at 2,450 feet. Below this is 200 feet of massive limestone. The Dodge horizon is a 15-foot limestone under blue shale and overlying a variegated shale. It has a porous streak containing low-grade oil of 35° Bé. Several small wells are producing from this horizon.

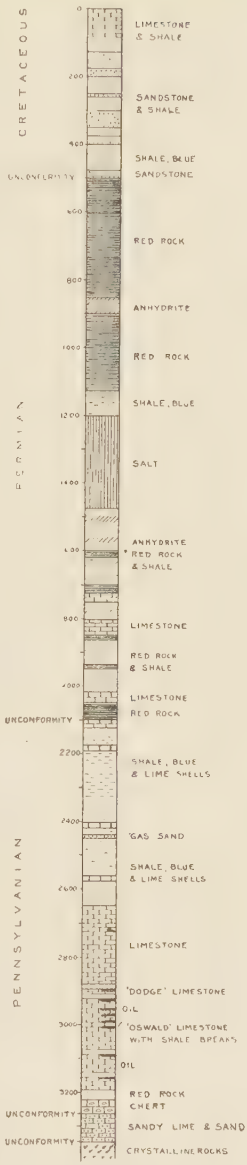


FIG. 2.—Columnar section, Fairport oil field, Russell County, Kansas. Depths shown in feet.

The base of the variegated shale marks the top of the Oswald horizon, which contains many streaks of high-grade oil of 40°–42° Bé. There are several shale breaks or partings in the limestone from the top of the Oswald horizon to

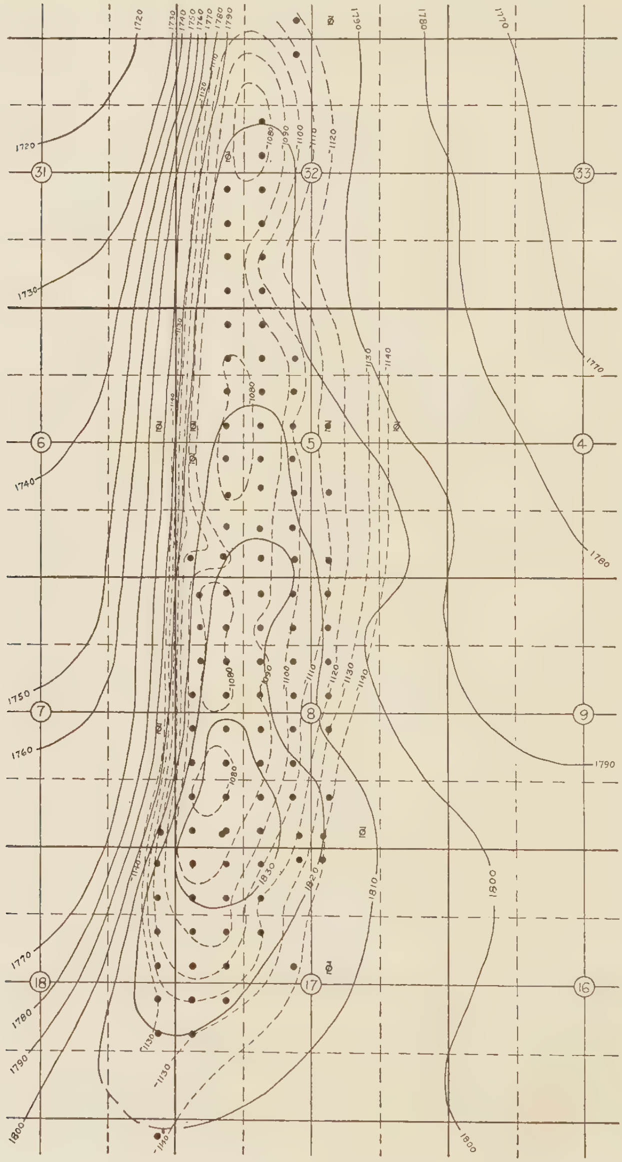


FIG. 3.—Map of Cretaceous and Pennsylvanian structure, Fairport oil field, Russell County, Kansas. March, 1927. (Thomas H. Allan.) Contour interval, 10 feet. Datum, sea-level. Cretaceous structure, full lines; Pennsylvanian structure, broken lines. Location of the discovery well, M. M. Valerius Oil and Gas Company's Oswald No. 1, is SW. cor., SE. ¼, Sec. 8.

the base of the Pennsylvanian. The basal member of the Pennsylvanian is a sandy lime containing much cherty material. This material appears to be re-worked Ordovician or older rocks and indicates a great unconformity. The pre-Pennsylvanian is mostly sand and sandy lime, probably Ordovician or Cambrian in age. Beneath this is a crystalline rock containing quartz, mica, chlorite, and granitic particles.

SURFACE STRUCTURE

The surface structure as shown in the Greenhorn limestone is the largest and best structure known in this area. The structure stands above the regional plane of the Greenhorn limestone and is 4 miles long with an east dip of 40 feet to the mile and a west dip of 50 feet in one quarter of a mile (Fig. 3).

SUBSURFACE STRUCTURE

The structure becomes sharper with depth, and on the Oswald horizon (2,900 feet deep) the dips are about four times as steep as those on the surface. Figure 3 shows the relation of surface structure to that on the oil-bearing horizon. The axis has moved about one location westward, and the steep west dip is so straight that it seems to have been caused by the Pennsylvanian sediments being deposited on a fault escarpment in the older rocks.

From the few wells drilled deeper it appears that the pre-Pennsylvanian rocks are much more steeply folded, and of Cambrian and Ordovician age, overlying a buried hill in crystalline rocks (Fig. 4).

RESERVOIR ROCKS

The oil occurs in porous streaks in the limestone. These porous streaks seemingly are caused by the circulation of water. Their thickness ranges from a few inches to a few feet. They are found at the top, and 30, 45, 65, 85, 98, 160, 175, and 220 feet below the top of the Oswald horizon. Uneven porosity is evident, as each well has a different history in each streak. The wells have different initial productions, decline at different rates, and miss some of the "pays" entirely. A well in a pay streak where the porosity is great has a higher initial production than where the porosity is small, and maintains its production longer where the porosity extends away from the well than where the porosity is local around the well.

RELATION OF ACCUMULATION TO STRUCTURE

The oil has accumulated on top of the structure surrounded by water five times as salty as sea water. The production extends 60 feet down the

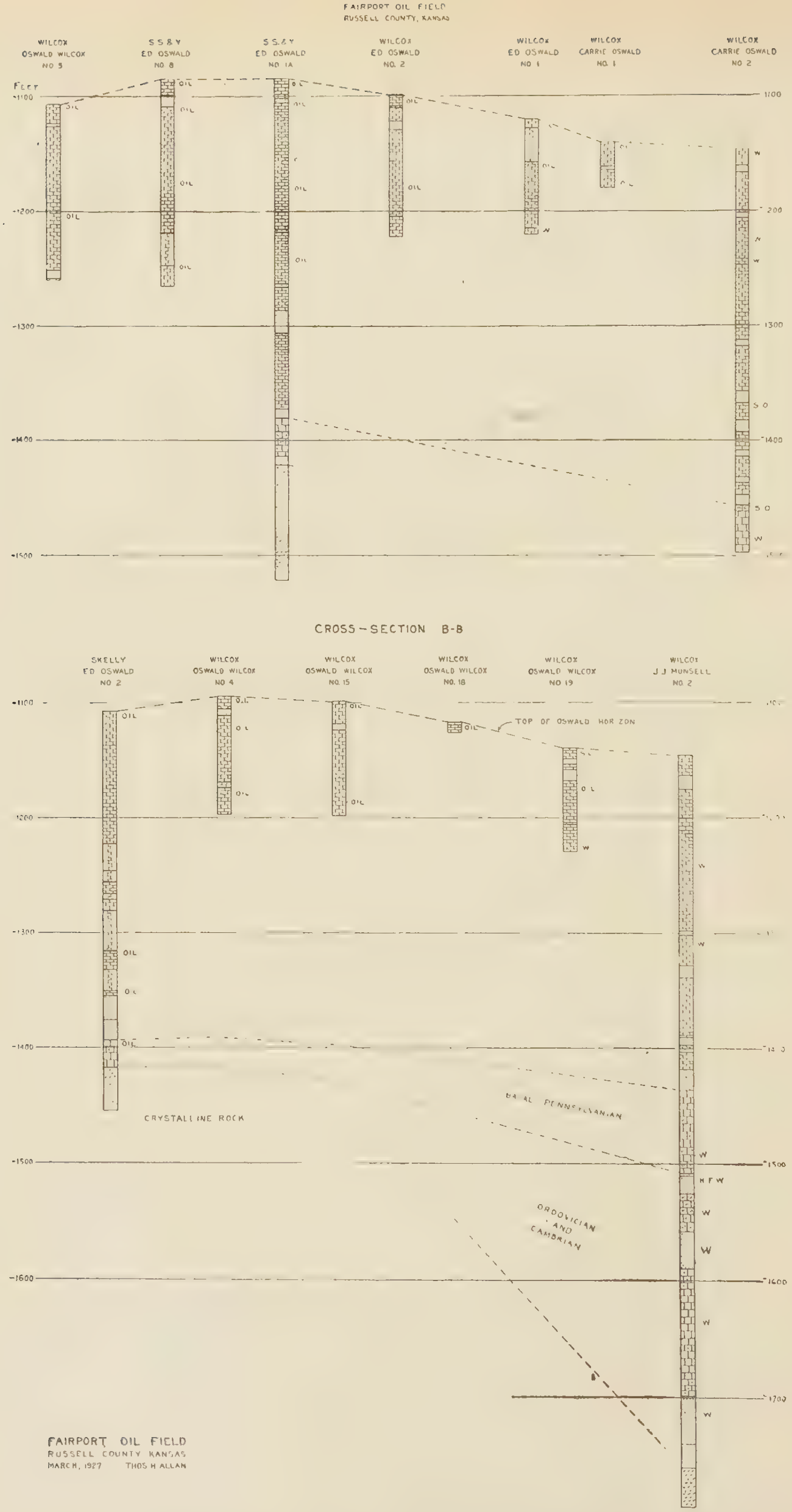


FIG. 4.—Cross sections *A-A* and *B-B*, Fairport oil field, Russell County, Kansas. Depths shown in feet. Location of sections is shown in Figure 1.

east and south sides in Sections 8 and 17, but only 30 feet down the east side and 10 feet down the west side in Section 5. Production will probably not extend far down the north end, as the two wells farthest north are producing from the Dodge low-gravity "pay," having obtained water in the top part of the Oswald horizon.

PRODUCTION

The Fairport field has been producing for three years, has been drilled up for six months, and has produced about 3,500,000 barrels of 40° Bé. black oil. Figure 5 shows the daily production of the field, the number of wells producing, and the daily average per well. The southwest quarter of Section 8 has the highest production per acre, 6,400 barrels, due to having the oldest wells and obtaining high initial production while the oil pressure of the field remained high. The field has averaged 3,500 barrels per acre to date.

By M. M. Valerius

The producing "sands" in the Fairport field are, as described in the preceding part of this paper, porous streaks in a limestone series locally known as the "Oswald lime."

During the early stages of development in the Fairport field, a correlation of the Oswald horizon was made by the State Geological Survey of Kansas. The correlation would appear to have been based partly upon paleontologic evidence, and partly upon the stratigraphic position of the Oswald as indicated by a cross section carried westward from Marion County (Figs. 6 and 7). As a result of the studies conducted, the Kansas Survey definitely correlated the Oswald horizon with the Oread member of the Douglas formation. This correlation has been, and is, generally accepted without comment.

Since the correlation by the Kansas Survey, much new material has been furnished for correlation studies by the completion of numerous tests in the region. Samples from the more recent wells have yielded many fossils which, according to Bruce Harlton,[1] show conclusively that the Oswald is not a correlative of the Oread but in reality occurs at the top of the Lansing formation. The stratigraphic position of the Oswald at the top of the Lansing is further proved by the results obtained in the careful cross section studies of C. A. Cheney,[2] who has carried an accurate cross section westward from the Nemaha Mountains (Figs. 8 and 9).

[1] Paleontologist, Amerada Petroleum Corporation, Tulsa, Oklahoma.

[2] Consulting geologist, Tulsa, Oklahoma.

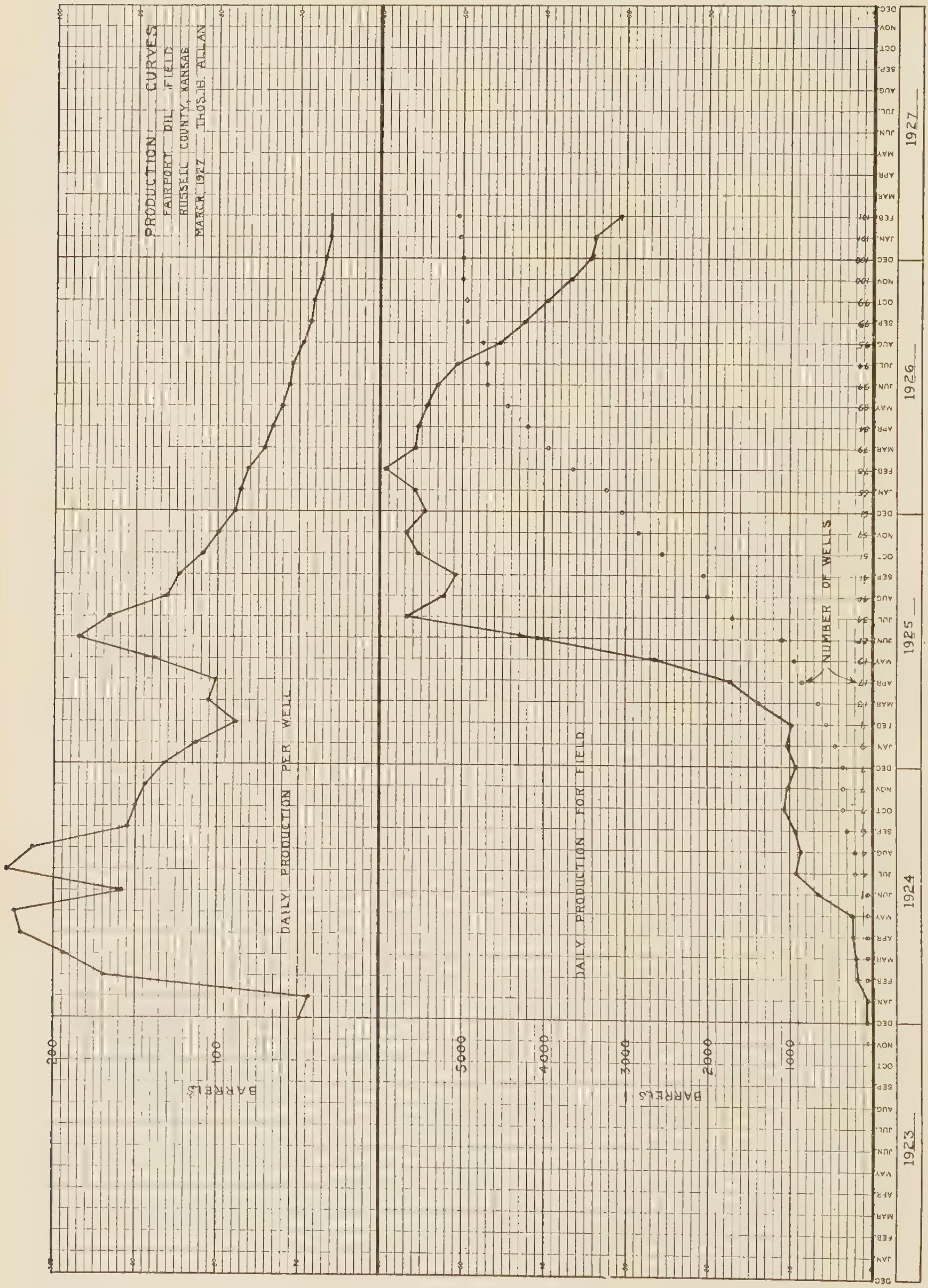


FIG. 5.—Production curves, Fairport oil field, Russell County, Kansas.

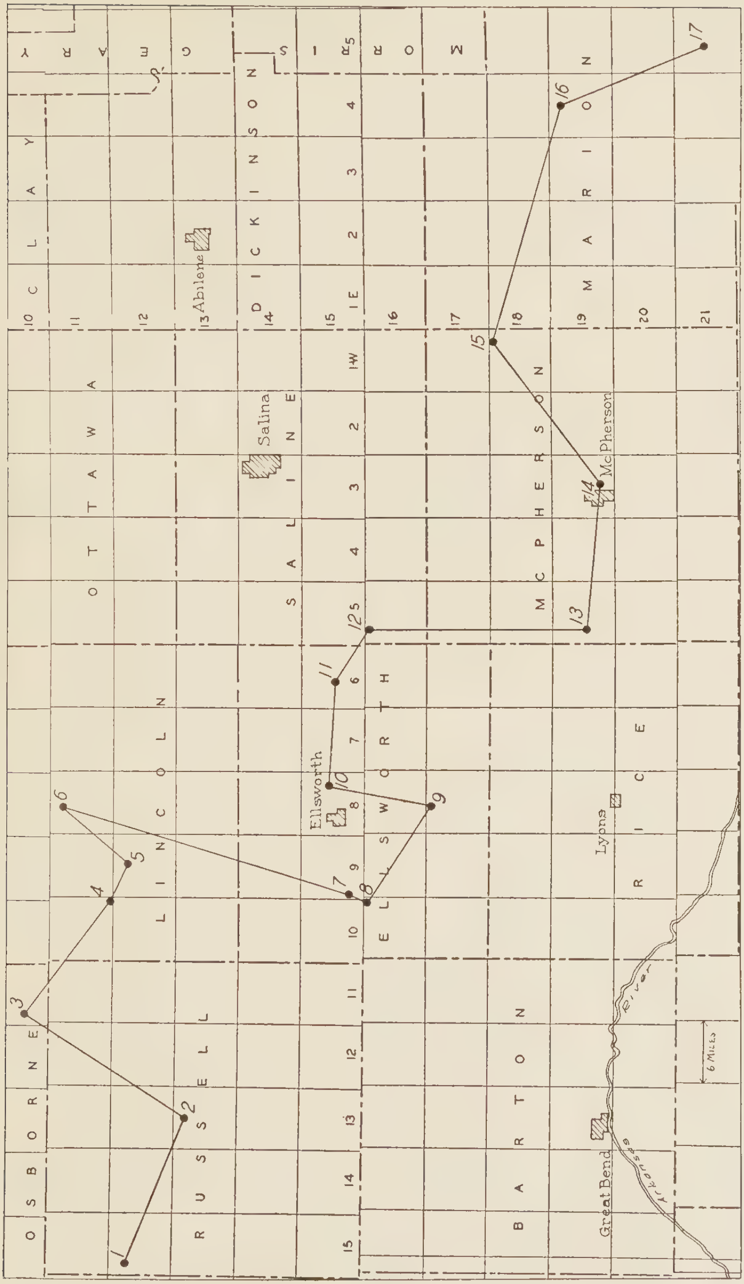


Fig. 6.—Location of cross section which is shown in Figure 7. From *State Geol. Survey of Kansas, Bull. X*, Plate VI. (Error in township numbering corrected.)

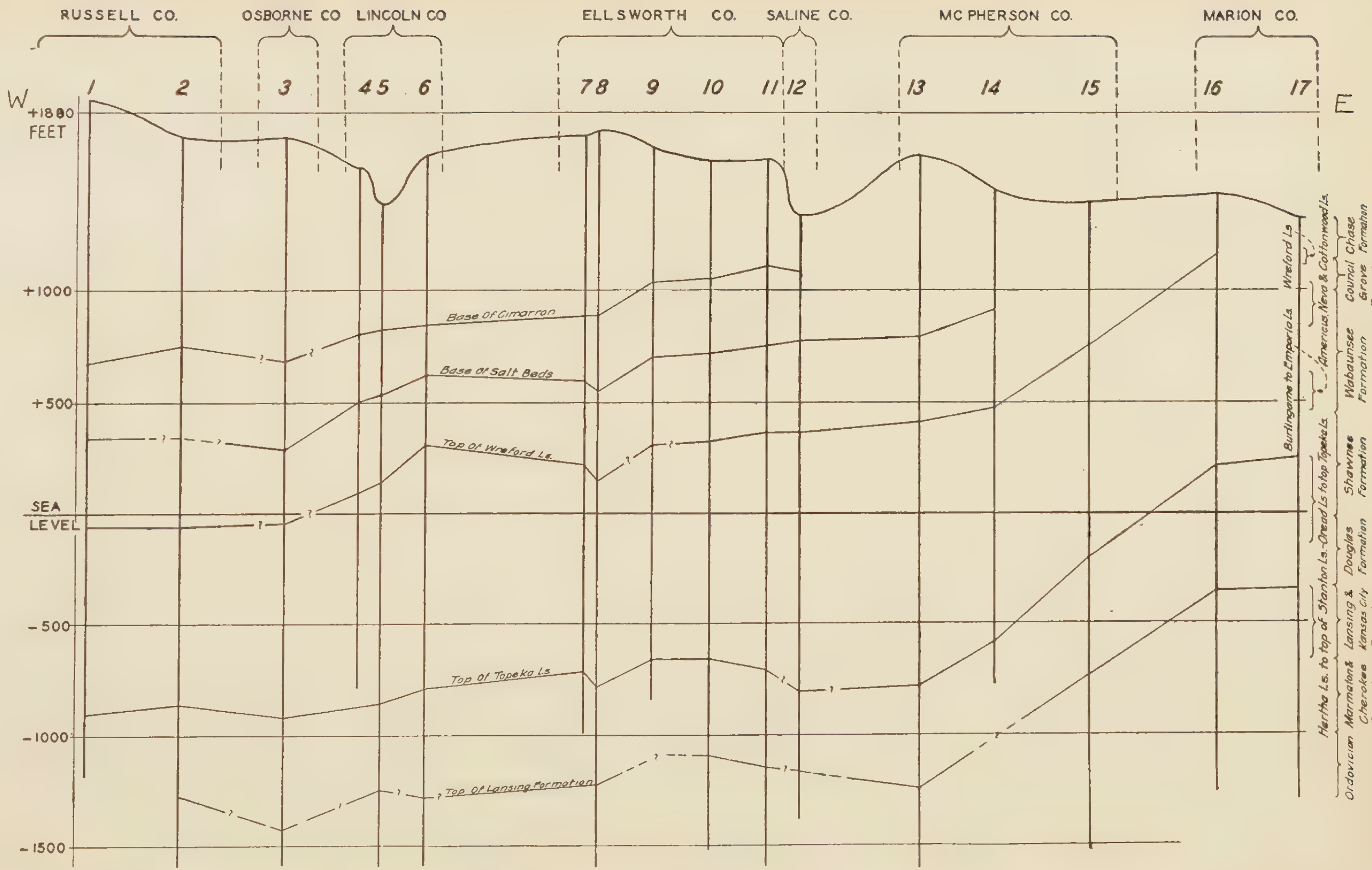


FIG. 7.—Skeleton cross section taken from *State Geol. Survey of Kansas, Bulletin X*, Plate VI. See Figure 6 for location of cross section. Correlation of well records, showing tentative determinations of geologic units extending from Marion County into Russell County, Kansas.

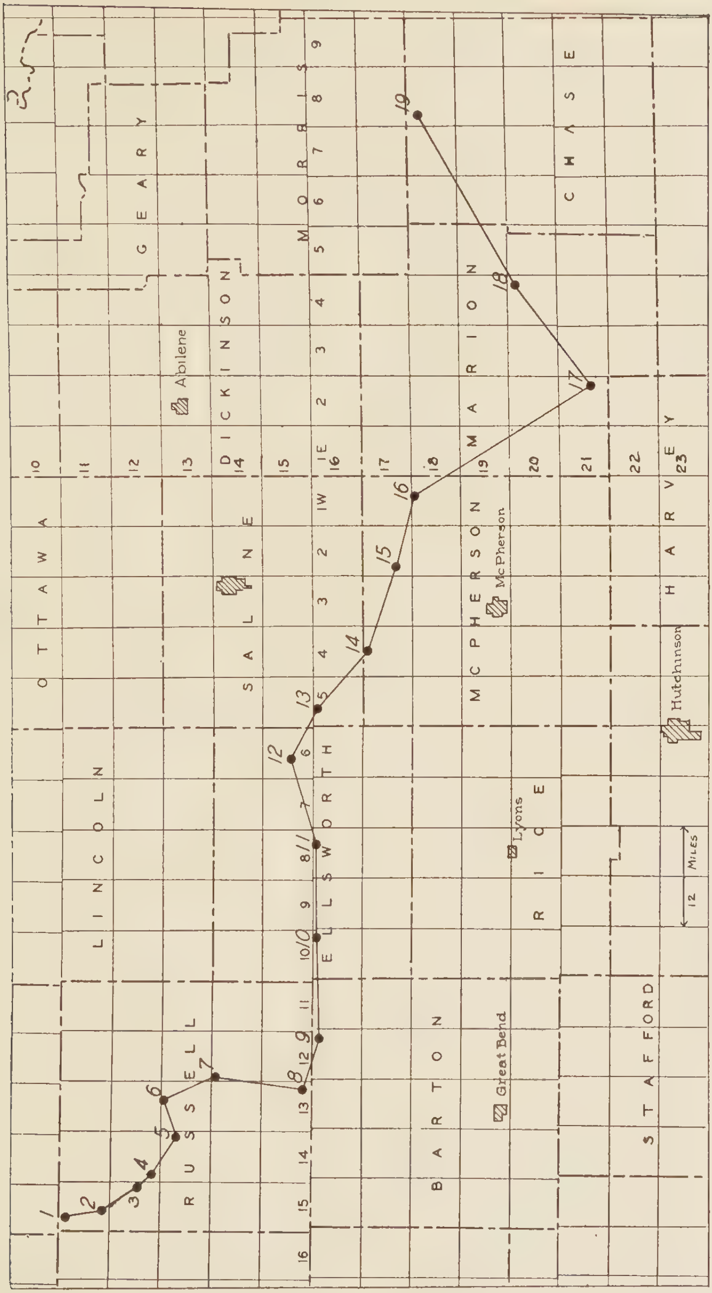


FIG. 8.—Map showing location of wells used in cross section which is shown in Figure 9.

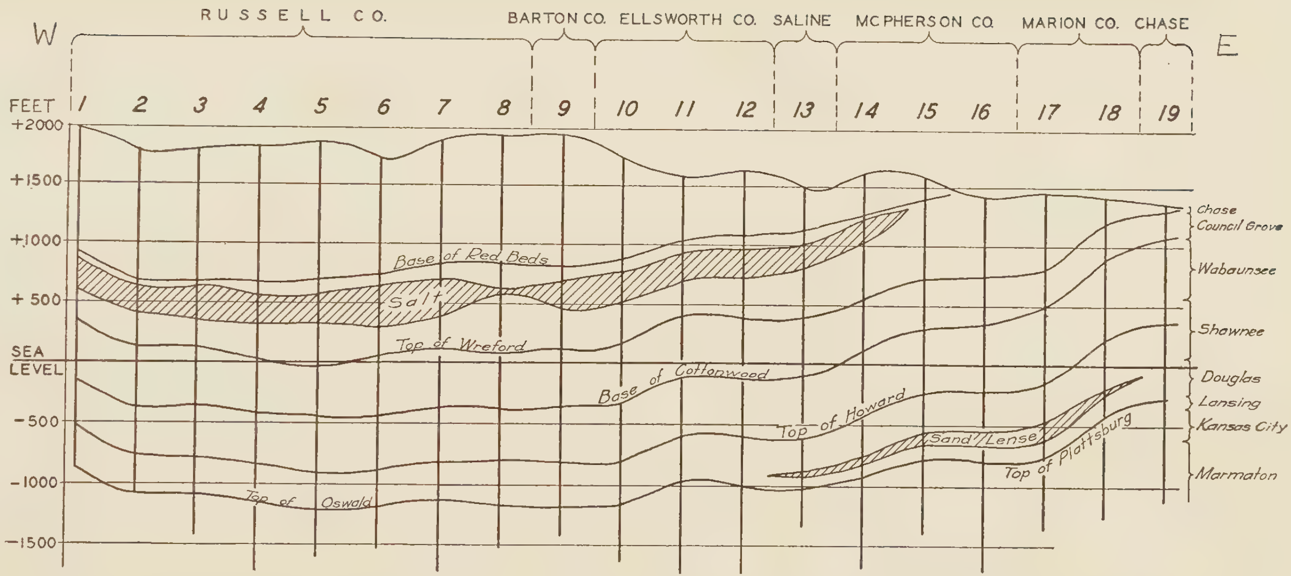


FIG. 9.—Cross section from Russell County to Chase County, Kansas. See figure 8 for location. Identification of wells:

1	Sec. 5, T. 11 S., R. 15 W.	T. C. Johnson	Kollman No. 7
2	Sec. 32, T. 11 S., R. 15 W.	Derby Oil Co.	Dodge No. 4
3	Sec. 24, T. 12 S., R. 15 W.	Producers & Refiners	Haise
4	Sec. 31, T. 12 S., R. 14 W.	Lewis Oil Co.	Haise No. 1
5	Sec. 13, T. 13 S., R. 14 W.	Prairie Oil & Gas Co.	Hill No. 1
6	Sec. 3, T. 13 S., R. 13 W.	M. M. Valerius Oil & Gas Co.	Phillips No. 1
7	Sec. 6, T. 14 S., R. 12 W.	Shoemaker-Townsley	Lindsay No. 1
8	Sec. 36, T. 15 S., R. 13 W.	Alcorn	Fellens No. 1
9	Sec. 11, T. 16 S., R. 12 W.	Orlando Petr. Co.	Schauf No. 1
10	Sec. 1, T. 16 S., R. 10 W.	Carter Oil Co.	Doubrava No. 1
11	Sec. 3, T. 16 S., R. 8 W.	Phillips Petr. Co. & Wrightsman	Kunkle No. 1
12	Sec. 21, T. 15 S., R. 6 W.	Keys Petr. Co.	Sheridan No. 1
13	Sec. 5, T. 16 S., R. 5 W.	Skaer Crum Oil Corp.	Peterson No. 1
14	Sec. 9, T. 17 S., R. 4 W.	Linsburg Oil & Gas Co.	Sangren No. 1
15	Sec. 29, T. 18 S., R. 2 W.	Merriam, Reeves & Shidel	Anderson No. 1
16	Sec. 2, T. 18 S., R. 1 W.	Mountain States Oil Co.	Clark
17	Sec. 26, T. 21 S., R. 2 E.	Pierce *et al*	Brogdon No. 1
18	Sec. 11, T. 20 S., R. 4 E.	(From *Bulletin 3, Geol. Survey of Kansas*)	Mehl No. 1
19	Sec. 8, T. 18 S., R. 8 E.	Robt. Watchorn	Patton

The partial columnar sections (Fig. 10) are typical of the Fairport field. As will be noticed in the Austin No. 1, the Shawnee formation extends from a depth somewhat less than 2,190 feet to a depth of 2,665 feet; the Douglas (at the top of which is the Oread horizon) occurs be-

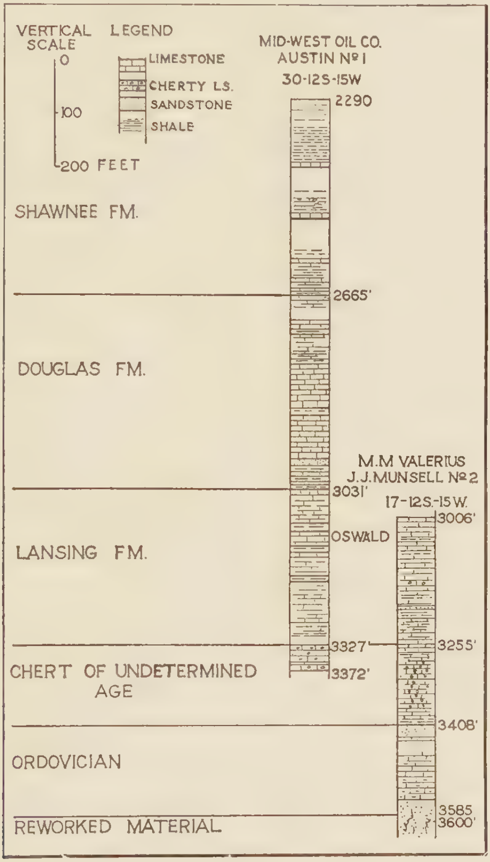


FIG. 10.—Partial columnar sections typical of the Fairport field. Munsell No. 2 is now owned by the Wilcox Oil and Gas Company.

tween the depths of 2,665 feet and 3,031 feet; and the Lansing, with the Oswald at the top, occurs between the depths of 3,031 feet and 3.327 feet. This correlation is based upon the identification of fossils.

Munsell No. 2 of the H. F. Wilcox Oil & Gas Company has been drilled to a total depth of 3,645 feet. From the base of the Lansing (3,255

feet) to a depth of 3,408 feet, the drill penetrated cherty limestones, shales, and sandstones, the cherty limestones predominating. This section is of undetermined age. From 3,408 feet to 3,585 feet occur sandy dolomites and sandstones of undoubted Cambro-Ordovician age. The bottom 60 feet of hole was drilled in re-worked material, in part arkosic. It would appear that the bottom of this hole was not far above the top of the pre-Cambrian which has been found in several wells in the field.[1] The driller's log of Munsell No. 2 is given in Figure 4 with essentially the same correlations.

The age of the Ordovician section is Decorah[2] which is equivalent to the Tyner formation of Oklahoma.

[1] Granite or granitic material has been found in three wells in the field at the depths indicated in feet:

Skelly Oil Co., Oswald No. 2, Sec. 18, T. 12 S., R. 15 W., 3,282 to 3,286.
Wilcox Oil & Gas Co., Munsell No. 2, Sec. 17, T. 12 S., R. 15 W., 3,585 to 3,627.
Stearns, Streeter, and Findeiss, Sec. 20, T. 12 S., R. 15 W., 3,610 to 3,617.

Other wells in the vicinity have reached granite or granitic material:

Producers & Refiners Corp., Sec. 24, T. 12 S., R. 15 W., 3,605 to 3,855.
Prairie Oil & Gas Co., Sec. 13, T. 13 S., R. 14 W., 3,770 to 3,860.
Keys Petrol. Co., Mermis No. 12, Sec. 33, T. 13 S., R. 15 W., 3,298 to 3,328 (Gorham field).
Keys Petrol. Co., Baxter No. 15, Sec. 32, T. 13 S., R. 15 W., 3,298 to 3,322 (Gorham field).
Midwest Ref. Co., Mermis No. 4, Sec. 32, T. 13 S., R. 15 W., 3,321 to 3,326 (Gorham field).
Producers & Refiners Corp., Sec. 9, T. 14 S., R. 15 W., 3,055 to 3,327.

[2] Jon A. Udden, "Occurrence of Ordovician Sediments in Western Kansas," *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), pp. 634–35.

COFFEYVILLE OIL FIELD, MONTGOMERY COUNTY, KANSAS[1]

W. H. FOSTER[2]
Tulsa, Oklahoma

ABSTRACT

The Coffeyville oil field is located in the southeast corner of Montgomery County, Kansas, on the Oklahoma state line. It was the first of the so-called "deep fields" in that locality. The field has produced approximately 265,000 barrels of 24° Bé. gravity oil from the top of the "Siliceous lime." The oil occurs in a well-defined dome. The field has not been as profitable as it should have been on account of too close spacing of wells.

HISTORY

The Coffeyville field is located in Sec. 17, T. 35 S., R. 17 E., Montgomery County, Kansas, and in Secs. 15 and 16, T. 29 N., R. 16 E., Nowata County, Oklahoma.

For several years previous to the discovery of oil this field produced shallow gas in considerable quantities. Charles O. Doub made a study of the logs of the gas wells and proved the existence of a small but excellent subsurface dome. The Red Bank Oil Company, in September, 1923, drilled the discovery well. This well, at a depth of 1,216 feet, was completed with an initial production of 150 barrels. Subsequently twenty-one other oil wells were drilled in this field.

STRUCTURAL GEOLOGY

The Coffeyville structure can be worked from surface limestone beds. It is a gently dipping dome with about 40 feet of closure. Subsurface contours on the Oswego limestone, Mississippian limestone, and "Siliceous" limestone, respectively, show the position of the apex of the dome farther and farther west with depth. They also show an increase in the degree of dip with depth. It is interesting to notice that a well drilled on the top of the surface structure would not have produced in the "Siliceous" limestone.

PRODUCING HORIZONS

The oil in the Coffeyville field lies immediately below the Chattanooga shale in the upper few feet of the "Siliceous lime" (Fig. 1). This

[1] Presented by title before the Association at the Tulsa meeting, March 26, 1927. Manuscript received by the editor, July 1, 1928.

[2] 915 Mid-Continent Building.

section of the lime is brown or gray and very porous. Immediately below this zone the lime is characteristically white with little porosity. This

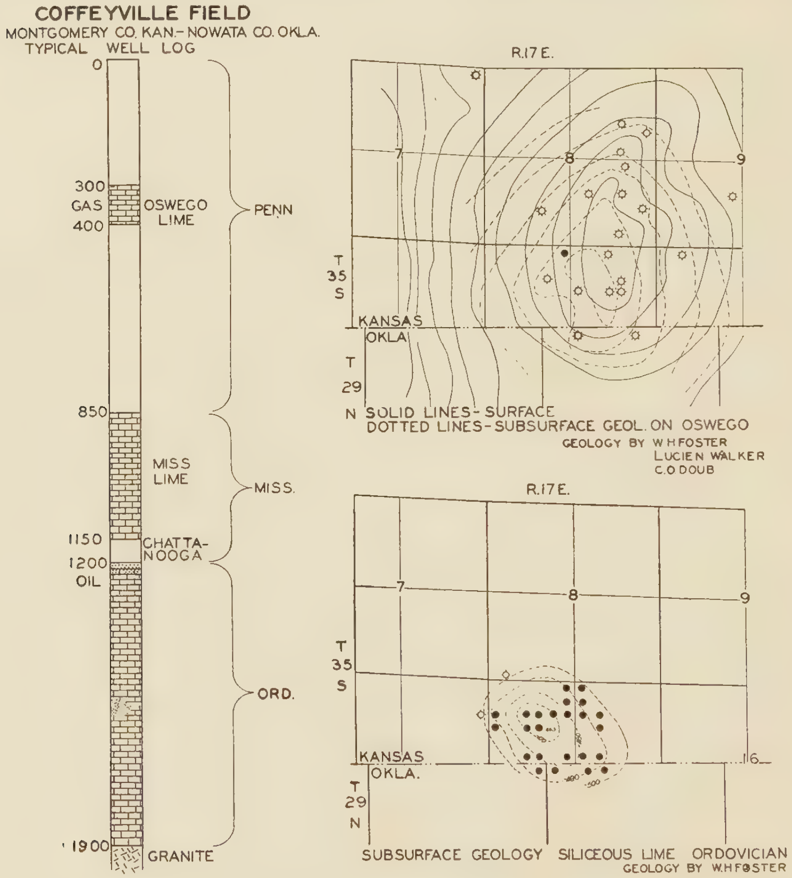


FIG. 1.—Surface structure map and subsurface structure maps of the Oswego and the "Siliceous" limestones, with type well log, Coffeyville field, Montgomery County, Kansas. Surface contour interval, 10 feet. Subsurface contour interval on the Oswego, 10 feet. Scale of vertical section shown in feet.

porous zone is due to the erosion of the Ordovician lime beds before the deposition of the Chattanooga shale.

The oil in this field probably originated in the black and highly carbonaceous Chattanooga shale.

The Red Bank Oil Company's George Lowry No. 1, one of the highest wells structurally in the field, after producing for some time from the

top of the "Siliceous lime," was drilled to a total depth of 1,890 feet. This well encountered 700 feet of "Siliceous lime" with almost no porosity. When abandoned it was probably not far from granite.

OIL PRODUCTION

All the wells in the Coffeyville pool were drilled with standard tools and stopped when the "pay" was penetrated from 2 to 5 feet. The average initial production was about 200 barrels, with a rapid decline and increase of water. There was very little gas with the oil. The oil is high in lubricants and until recently brought a price much higher than most other oils of the same gravity. It was shipped by tank car to the refineries of the Standard Oil Company of Indiana at Whiting, Indiana. The analysis is here shown.

ANALYSIS OF OIL FROM COFFEYVILLE FIELD, KANSAS

(Gravity 24.7° Bé.)

	Percentage	
Benzene	2.00	
Kerosene	5.83	
Gas oil	7.66	Cracking stock
Wax distillate	30.00	60.99
Fuel oil	53.45	
Loss	1.02	

The field covers approximately 200 acres. To date the total production has been about 265,000 barrels, or a yield of 1,350 barrels per acre. If not more than ten wells properly spaced had been drilled, instead of twenty-two, this small field would have returned an excellent profit.

RAINBOW BEND FIELD, COWLEY COUNTY, KANSAS[1]

D. R. SNOW AND DAVID DEAN
Tulsa, Oklahoma

ABSTRACT

The Rainbow Bend oil field is located near the west line of Cowley County, Kansas, about midway between Arkansas City and Winfield. Since its discovery in December, 1923, approximately 9,000,000 barrels of oil testing about 41° Bé. gravity have been produced. The oil comes from sand at the very base of the Pennsylvanian, and production seems to be controlled by the distribution of this sand, which is lenticular. A well-defined, anticlinal dome is defined by the top of the Mississippian limestone, the oil sand occurring on the southeast flank of this fold. Development is controlled by one company; consequently, there is no overdrilling. Casinghead gasoline is an important product from the wells.

The Rainbow Bend field of Cowley County, Kansas, was the first field of commercial importance to be opened between the old Augusta and Blackwell oil fields. Since its discovery in December, 1923, the field has produced more than 2,000,000 barrels[2] of oil of approximately 41° Bé. gravity. Thirty-one wells have been completed with an average daily initial production of more than 1,000 barrels[2] per well without shooting. The field is now making nearly 12,500 barrels daily. There are 28 drilling wells,[2] most of which are inside proved locations, and from present indications this field gives promise of developing into a field of considerable importance.

A much higher daily output would undoubtedly have been reached but for the fact that the entire block is owned and controlled as a unit by three companies. Waite Phillips Company, which owns a half-interest, operates the property. The Marland Oil Company, and the Independent Oil and Gas Company, each own a one-quarter interest.

The writers have watched the development of the field in the interest of Waite Phillips Company and are indebted to them for the privilege of presenting this paper.

LOCATION

The Rainbow Bend field is located in T. 33 S., R. 3 E., Cowley County, Kansas, in the center of a 3,500-acre block which occupies a large

[1] Reprinted in part from *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 9, No. 6 (September, 1925), pp. 974–82.

[2] For revised figures in 1928, see the subsequent note to this paper, p. 58.

bend in Arkansas River, locally known as Rainbow Bend—hence the name of the field.

HISTORY

Martin W. Baden, of Winfield, originally assembled this block and made a favorable geological report to Johnson D. Hill, of Okmulgee, who jointly with the Independent Oil and Gas Company contracted to drill a 3,000-foot test. When Mr. Hill became affiliated with the Waite Phillips Company in 1923, this company acquired his half-interest in the project.

No oil was found at 3,000 feet, and the well was drilled deeper, tapping the "pay" at 3,198 feet, and the discovery well was completed in December, 1923, as a 350-barrel flowing well.

Several months later the Marland Oil Company purchased one-half of the Independent's half-interest, and laid a pipe line to the field from their Ponca City refinery. This line has taken all of the oil from the Rainbow Bend field until recently, when the Waite Phillips Company started running part of their production to their own refinery at Wichita.

Several of the larger companies, recognizing the importance of the discovery, moved core drills into the area, and as a result the Marland Oil Company located and drilled their Graham No. 1 in the northeast corner of Sec. 9, T. 33 S., R. 3 E., 3 miles northeast of the Rainbow Bend field. This well found only a sandy shale in the Rainbow Bend producing horizon, but it was completed in July, 1924, as a 900-barrel well in the top of the Ordovician "Siliceous" limestone. This was the first commercial producer found in this horizon in Cowley County. Eight wells have since been completed in this field, which is known as the Graham field, and there are at present [1925] 15 drilling wells in this vicinity. Several wells have also been completed in this area in the 2,550-foot sand.

GEOLOGY

SURFACE INDICATIONS OF STRUCTURE

Surface rocks in the Rainbow Bend area are chiefly alluvium, shale, and red rock. Evidence of surface structure is confined principally to a rotten, brecciated limestone which weathers into a very characteristic porous outcrop. This bed lies in the upper part of the Pearl shales about 70 feet above the Herington limestone. This is near the contact of the Marion and Wellington formations, which are of Permian age. This limestone, probably occupying the stratigraphical position of the Abilene conglomerate, can be followed from the north line of Sec. 7, T. 33 S., R. 3 E., southeast for about 3 miles along the west side of the river into the center of the southwest quarter of Section 20, of the same township.

No appreciable structure is evident on this ledge, the dips being irregular and the greatest difference of elevation being but 15 feet. However, $1\frac{1}{2}$ miles southeast under the river bridge in Section 21, there occurs a limestone bed of practically the same physical characteristics which is 20 feet lower in elevation than the bed in the Rainbow Bend. No fossils have been found in either of these limestone outcrops, and a definite correlation has not been made, but it is the writers' opinion that they are the same. As far as the writers know, this is the only surface evidence of a structure in Rainbow Bend.

STRUCTURE SHOWN BY CORE-DRILL

Waite Phillips Company has done no core drilling in this area, but from authoritative sources, it is understood that the Herington limestone shows a long, southwest-plunging nose whose axis conforms generally with the "Mississippi lime" axis through the Graham and Rainbow Bend fields, but whose dips are much less pronounced than those on the deeper formations.

SUBSURFACE STRUCTURE

The subsurface structure of this district, as shown on the general map in 50-foot contours on the top of the "Mississippi lime" (Fig. 1), indicates an axis of folding from the Clarke field in Sec. 6, T. 31 S., R. 4 E., extending south through the Rainbow Bend field to Blackwell. This same trend probably extends south through the Hubbard, Besdor, and Barnes fields to Garber. It is approximately parallel with a line drawn along the axis of the Granite Ridge and is probably closely associated with it in origin, although no granite has been found south of Oxford on this trend.

Along this general axis of folding, isolated structures of several types occur, of which the Graham and Rainbow structures are fair types.

Another interesting fact in connection with subsurface observations of this area is the difference in thickness of the Mississippian limestone with relation to structure. On the south and east sides of the field the lime is 100 feet thicker than on the crests of the folds. This causes much steeper dips on the Ordovician limestone than are shown on top of the Mississippian. A similar but not so pronounced difference is found in the Cherokee shale.

PRODUCING HORIZONS

Three producing sands are known in T. 33 S., R. 3 E. The shallowest, found at 2,550 feet in the Graham field, seems to be a spotted producer. Good showings have been found at this horizon in the Rainbow Bend

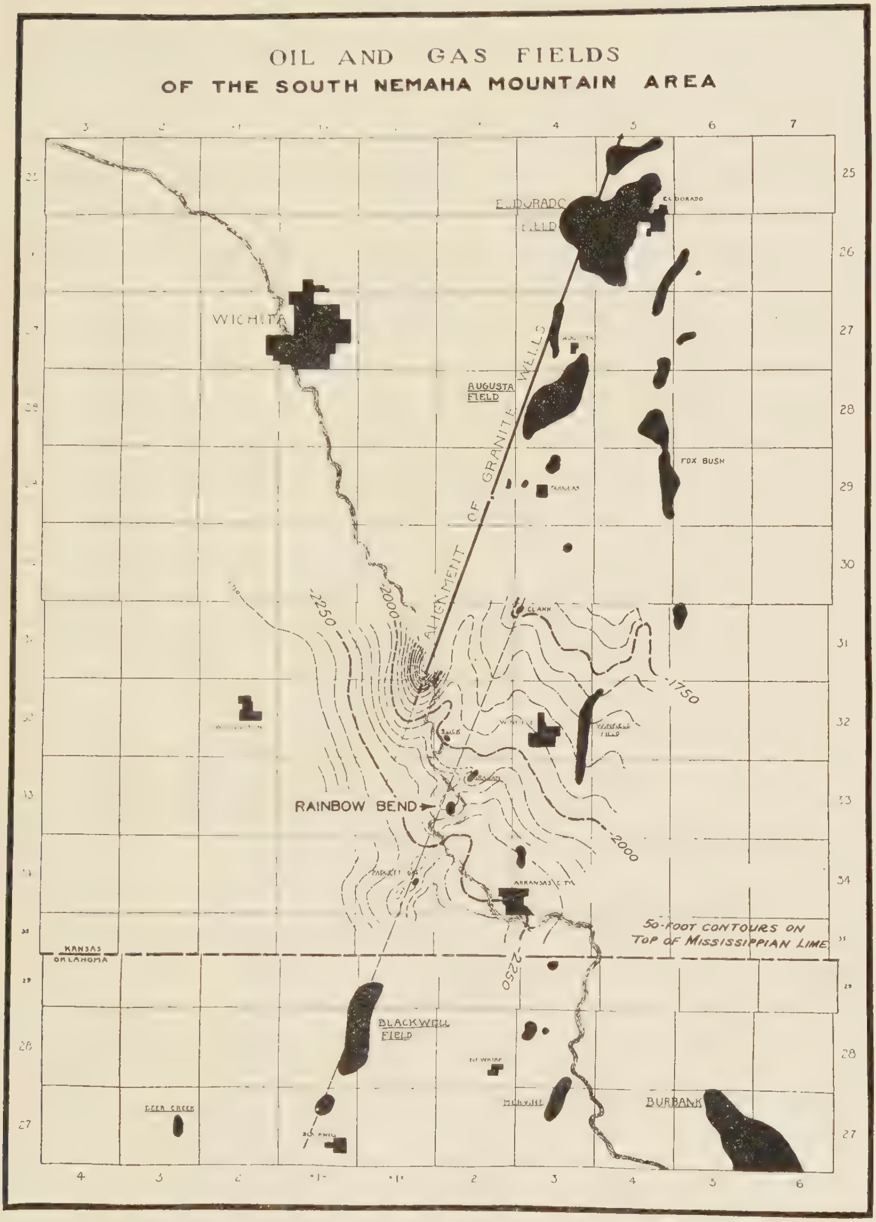


FIG. 1.—Oil and gas fields of the South Nemaha mountain area, Kansas. Width of area mapped, approximately 10 miles.

field, but no producers have been completed. This sand is producing in the Slick pool 6 miles north. It lies in the upper sandy member of the Kansas City formation, and is correlated with the Layton sand of Oklahoma, and the Stokes sand at Eldorado.

The second sand, and the most important, is found on top of the "Mississippi lime" and has been termed the Rainbow Bend sand. It has been thought better to name the producing horizon from the name of the field, as at Burbank, rather than from the farm on which the discovery was made. The writers believe that this sand can be referred consistently to the Burbank sand horizon of Oklahoma which has previously been correlated with the Bartlesville. These three sands evidently occupy the same horizon, although they cannot be shown to be continuous; therefore, they are given separate names.

A cross section from Burbank to Rainbow Bend shows that this sand is closely associated with a red-rock horizon, and that the thinning of the shale below the sand toward the northwest has brought the sand in contact with the Mississippian limestone in the Rainbow Bend field.

The Rainbow Bend sand is a true quartzitic sand of irregular hardness, depending largely on the amount of calcareous cementation. One specimen of this sand was obtained from the Glasgow No. 5 well on the west side of the field, and showed a porosity of 29 per cent, which is exceptionally high. This porosity is probably not representative of the field, as the sample was obtained when a gas pocket blew the sample of sand out of the hole.

The thickness of the Rainbow Bend sand ranges from 5 to 50 feet, thinning toward the crest of the "Mississippi lime" ridge and thickening toward the southeast. No water has yet been found in its base. Some water has shown in those wells which have been drilled several feet into the Mississippian limestone.

The next important sand occurs at 3,500 feet in the top of the Ordovician "Siliceous" limestone. In many wells which have tested this horizon a thin film of "Wilcox" sand and green shales has been found between the Ordovician limestone and the Chattanooga shale. This productive siliceous limestone shows the same characteristics as at Eldorado and Augusta and presents a similar problem of closely associated sulphur water. At present [1925], this horizon is producing only in the Graham pool.

RELATION OF PRODUCTION TO STRUCTURE

Production in the Rainbow Bend field is very similar to that in the Burbank field in that it is controlled almost entirely by the character

and extent of the sand body. The largest wells occur on that part of the fold where the sand is thicker and more porous, which occurs from 30 to 50 feet below the highest parts of the sand body.

The sand in the Rainbow Bend field lies on the southeast slope of a prominent "Mississippi lime" ridge, and as far as the writers know this is the only occurrence of a productive sand body lying east of a lime "high" in this general area. The extent of this sand body will probably define the limits of the field.

Ordovician "Siliceous lime" production will probably bear the same relation to structure here as at Eldorado and Augusta. So far, this production has not given promise of any real importance, but the Marland Sheehan well in Section 34, which was correlated 297 feet lower than the Graham discovery well, and was estimated a 40-barrel pumper, suggests that this sand has possibilities of producing throughout a much larger area than is included in the present Graham field. One well in the Rainbow Bend field, the Patterson No. 1, has recently been drilled to this horizon without yielding production.

PRODUCTION YIELD PER ACRE

For the area already proved, approximately 640 acres, the probable yield per acre will be about 12,000 barrels. This is considerably greater than the average yield per acre at Burbank, but the natural initial production per well in the Rainbow Bend field is also much larger than the average for the whole field at Burbank. As the proved area increases, this estimate per acre will probably be reduced because of poorer production on the edges of the field, and the relief of gas pressure through present producing wells.

CASINGHEAD-GASOLINE PRODUCTION

A casinghead-gasoline plant has recently been completed, and is producing approximately 15,000 gallons per day. This plant is being enlarged to a capacity of 30,000 gallons per day. There are approximately 25,000,000 cubic feet of casinghead gas available from the Rainbow Bend sand at the present time [1925]. The average yield per thousand cubic feet of gas is now about 2.0 gallons of Grade A gasoline, and will no doubt greatly increase as the field increases in age. It is estimated that the plant can be operated at a capacity of 30,000 gallons per day for 2½ years from the gas of the present proved area before production will be decreased from diminished gas. It is also estimated that the value of the casinghead-gasoline production is approximately 25 per cent of the value of the oil production.

SUBSEQUENT NOTE[1]

D. R. Snow[2]
Tulsa, Oklahoma

The original paper describing the Rainbow Bend field was presented at the Wichita meeting of the American Association of Petroleum Geologists in March, 1925, by the writer, jointly with David Dean. Since that time the field has been completely developed in the Rainbow sand horizon which is correlated with the Burbank and Bartlesville sand horizon. Approximately 110 producers were completed in the Rainbow sand, from which approximately 9,000,000 barrels of oil have been produced. The field is now making approximately 1,500 barrels per day, and unless other than natural production methods are used, the total recovery per acre will not exceed 10,000 barrels per acre. Natural-gasoline production is still more than 10,000 gallons per day, but is declining rapidly. Ideas concerning the relation between structure and accumulation have not been changed by drilling development since 1925, production being governed by the condition of the sand, which in this field is a lensed body, grading into shale in all directions and lying on the southeast flank of a Mississippian ridge whose axis extends northeast and southwest.

Approximately 1 mile north of the Rainbow sand area a new structural "high" has been located recently and has produced two wells of moderate size from the "Siliceous lime" horizon. The discovery well in this area had an initial production of 300 barrels, and the second location on the northwest, an initial production of 600 barrels. Both of these wells declined rapidly, however, and are now making about 50 barrels of oil per day, together with a large amount of water. Three other wells, which should define the structure closely, are now being drilled to the "Siliceous lime," mainly because of expiring leases. The accompanying map (Fig. 2), prepared with the top of the Mississippian as datum, gives the structural features of the Rainbow and "Siliceous lime" areas as they have been defined to date. The data for this map were furnished by R. B. Rutledge, of the Wichita office of the Barnsdall Oil Company.

[1] Manuscript received by the editor, January 6, 1928.

[2] Chief geologist, Barnsdall Oil Company.

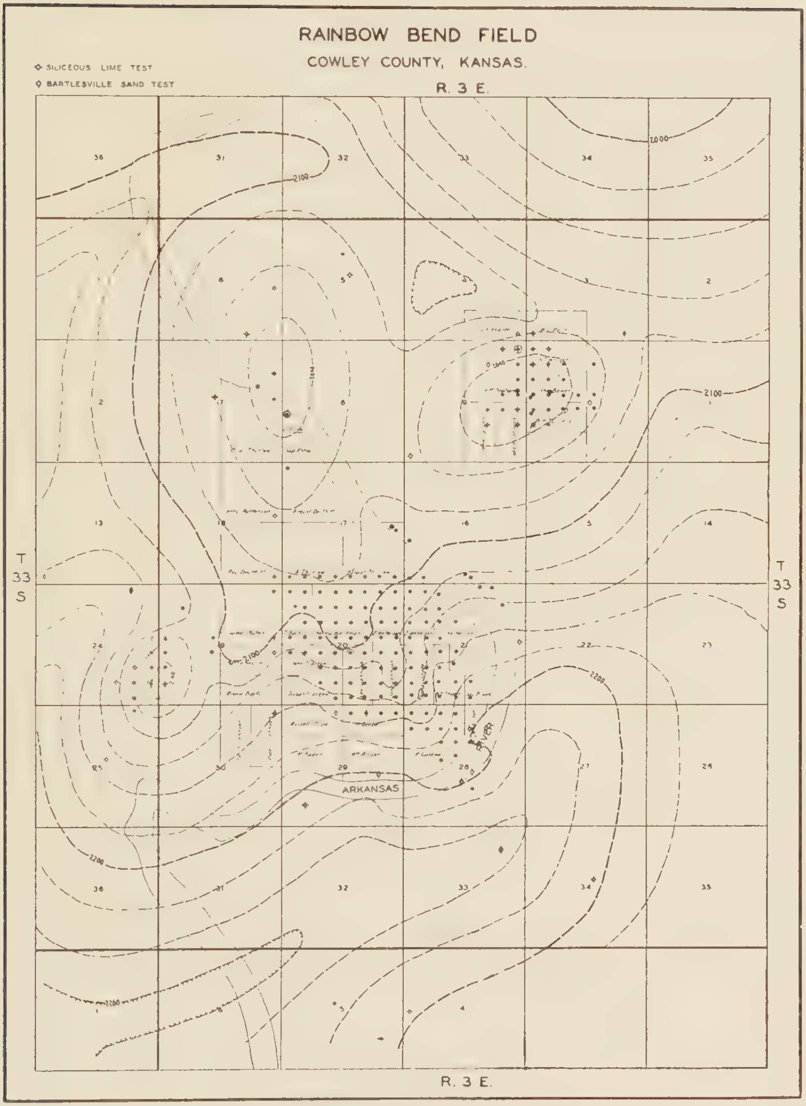


FIG. 2.—Subsurface structure map of the top of the Mississippian limestone, Rainbow Bend field, Cowley County, Kansas. Width of area mapped, approximately 6 miles.

FLANK PRODUCTION OF THE NEMAHA MOUNTAINS (GRANITE RIDGE), KANSAS[1]

C. R. THOMAS[2]
El Dorado, Kansas

ABSTRACT

In this paper surface and subsurface maps of an area comprising six townships and four producing fields are shown. From these and other data it is concluded that these producing folds are anticlinal buried hills and are contemporaneous with the Nemaha Mountains. Surface geology was largely responsible for the development of this area. The subsurface folds directly underlie the surface folds with remarkable consistency.

The conclusion is drawn that the surface folds are due to differential settling and depositional dip of the upper horizons over the Ordovician buried hills. The principal producing horizon is the unconformable contact between the Ordovician and later sediments. Furthermore, it is concluded that the oil has migrated laterally for some distance from its source in the lower Pennsylvanian and Chattanooga shales to its present position.

INTRODUCTION

This paper covers four producing oil fields: Elbing, Peabody, Covert-Sellers, and Florence. It embraces an area of six townships: T. 21, 22, and 23 S., R. 4 and 5 E., Butler and Marion counties, Kansas.

The writer is indebted to the Amerada Petroleum Corporation, the National Refining Company, Lee and Garlough of Wichita, Kansas, and to the publications of the Kansas Geological Survey, from which sources he has drawn most of his information.

HISTORY

The first producing well in this area was Leydig No. 2, the second location south along the east side of the NW. $\frac{1}{4}$ of Sec. 18, T. 23 S., R. 4 E., in the Elbing field. The date of this discovery was about August 1, 1918.

The discovery in the Peabody field was Elmhurst Investment Company's O. Jolliffe No. 1, located in the south center of the SE. $\frac{1}{4}$ of the SE. $\frac{1}{4}$ of Sec. 9, T. 23 S., R. 4 E. This well was completed September, 1920.

The discovery in the Covert-Sellers field was Ward and Wilhoit's Covert No. 1, located in the southwest corner of the NE. $\frac{1}{4}$ of the NW. $\frac{1}{4}$

[1] Presented before the Association at the Tulsa meeting, March 25, 1927. Published by permission of the Amerada Petroleum Corporation. Reprinted from *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 9 (September, 1927), pp. 919–1031. Revised, October, 1928.

[2] Skelly Oil Company.

of Sec. 28, T. 21 N., R. 4 E. This well was completed about the middle of March, 1920.

Almost simultaneously with the discovery in the Covert-Sellers field, Robinson and Loreau brought in their Hupp-Greeley No. 1, located in the southwest corner of the SE. ¼ of Sec. 18, T. 21 N., R. 5 E., thus opening the Florence field.

STRATIGRAPHY

The beds exposed at the surface in this area are lower Permian (non-red) shales and limestones. From the lowest beds upward the divisions are as follows: Matfield shale, Florence flint, Fort Riley limestone, Doyle shale with the Towanda limestone member, Winfield limestone, Luta limestone, Enterprise shale, Herington limestone, and Pearl shale.

With the exception of the two highest horizons, the Herington limestone and the limestone bed of the Pearl shales, these are all very persistent beds. Local dips, which evidently have no bearing on the subsurface structure, are here and there found in the Herington limestone. The limestone bed of the Pearl shales is not continuous and can not everywhere be found. Fortunately this horizon is exposed only along the western part of this area; hence, its non-continuity interferes but little with the accurate mapping of the structure of the producing areas.

The subsurface stratigraphy is shown in Figure 4.

The principal producing horizon is the unconformable contact between the Ordovician and subsequent strata.[1]

[1] J. R. Reeves, El Dorado, Kansas, offers the following comments:

"No discussion is made of the Ordovician divisions. The 'Viola' or Joachim, and the St. Peter, present in the Florence field as cuttings from Prairie Oil and Gas Company's Urschell No. 4, Sec. 16, T. 21 S., R. 5 E., indicate as follows: 'Viola,' 2,320–2,440 feet; St. Peter, 2,440–2,550 feet, and 'Siliceous lime,' to 2,595 feet. This checks so well with the section as we know it a few miles north and south that there can be no question about the sequence or the formations. Where the area is painstakingly studied, other logs and cuttings are available which indicate the same.

"We can trace the 'Viola' from Oklahoma, through Kansas, to Missouri, near Kansas City. At least there is a cherty dolomitic lime at this horizon throughout Kansas. Below it is the rounded quartz sand formation persistently 55–60 feet thick throughout thousands of square miles in Kansas, which we can trace as we can the 'Viola.' In the basins in Kansas the Sylvan and Hunton, or beds in that position, are also persistently present and recognizable in large areas. I do not say our beds below the Mississippian are exact correlatives of the Oklahoma section, but they do occupy exactly the same positions. I call the Kansas 'Wilcox' St. Peter because we can trace it readily into Missouri and because it is so much closer to Missouri than the Arbuckle section. Probably Joachim fits our 'Viola' better than the Oklahoma Viola. I am not particularly desirous to correlate on lithologic bases, but so far we have no other choice."

The writer's reply follows:

"The subdivision of the Ordovician in this area on the lithologic characteristics as described by Reeves seems to me to be very well justified. However, since these correlations are based entirely on evidence other than paleontology, I do not wish to subdivide the Ordovician in this paper on this evidence, because there are many men who are more familiar with this section than I am and who are much better qualified to make such subdivision."

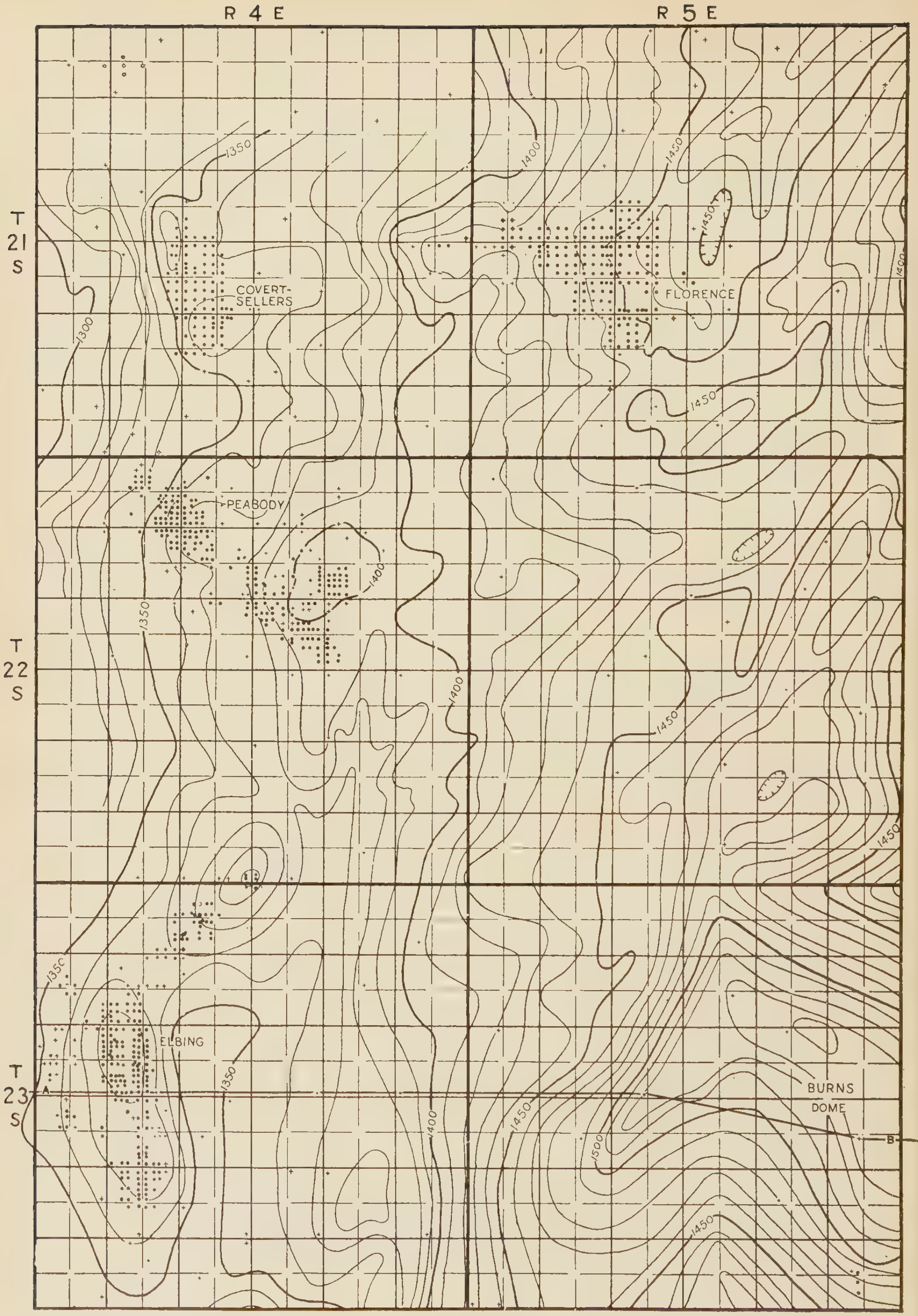


FIG. 1.—Surface structure of the Herington limestone. Contour interval, 10 feet. Scale, one township approximately 6 miles square. Compilation of work by the Kansas Geological Survey, the National Refining Company, the Empire Gas & Fuel Company, and the Amerada Petroleum Corporation.

SURFACE STRUCTURE

The normal dip of the rocks in this area is west at the rate of about 20 feet per mile. On the west and north sides are four anticlines which have been named in the first paragraph of this paper. Their axes are generally north and south, and the amount of closure ranges from 10 to 50 feet. In the southeast part of the area is the large Burns dome with closure amounting to 150 feet or more, which is typical of the surface expression of the Nemaha Mountains. These and other minor features are well shown in Figure 1.

As the normal dip is very slight and the surface folds of the producing fields are small, the recording of local dips for field work is of little benefit. Plane-table methods of mapping have proved the only profitable solution of structure problems in this territory.

Because of the excellent character of the key horizons used for plane-table mapping, it has been customary to use 5-foot contours to portray structure in this territory. The surface structure map (Fig. 1) is made with 10-foot contours, but was compiled from maps made with 5-foot contours. Consequently, with the possible exception of those points where one set of maps has been tied in to another set, this map should be accurate.

A very noticeable feature in connection with this surface map is the fact that the production conforms remarkably to the surface structure.

SUBSURFACE STRUCTURE

In subsurface mapping, the Lansing formation is probably the best horizon above the producing zone. This consists of several hundred feet of thick limestones and may readily be correlated in any well log that has been well kept.

Two subsurface structure maps accompany this paper. Figure 2 shows the structure of the top of the Lansing formation, and Figure 3, the structure and relief of the top of the Ordovician. The Ordovician rocks have undergone much erosion in parts of the area, so that Figure 3 actually represents the contour of the top of the Ordovician which is partly structure and partly relief. A comparison of the two maps shows much more closure (part of which is relief) on the Ordovician than on the Lansing formation. Further comparison with the surface-structure map shows a lessening of the amount of folding as the surface is approached.

The cross section *A–B* (Fig. 4), extending from the Elbing anticline to the Burns dome, indicates considerable shortening of the section over these folds. This shortening is due to the erosion of the Mississippian and

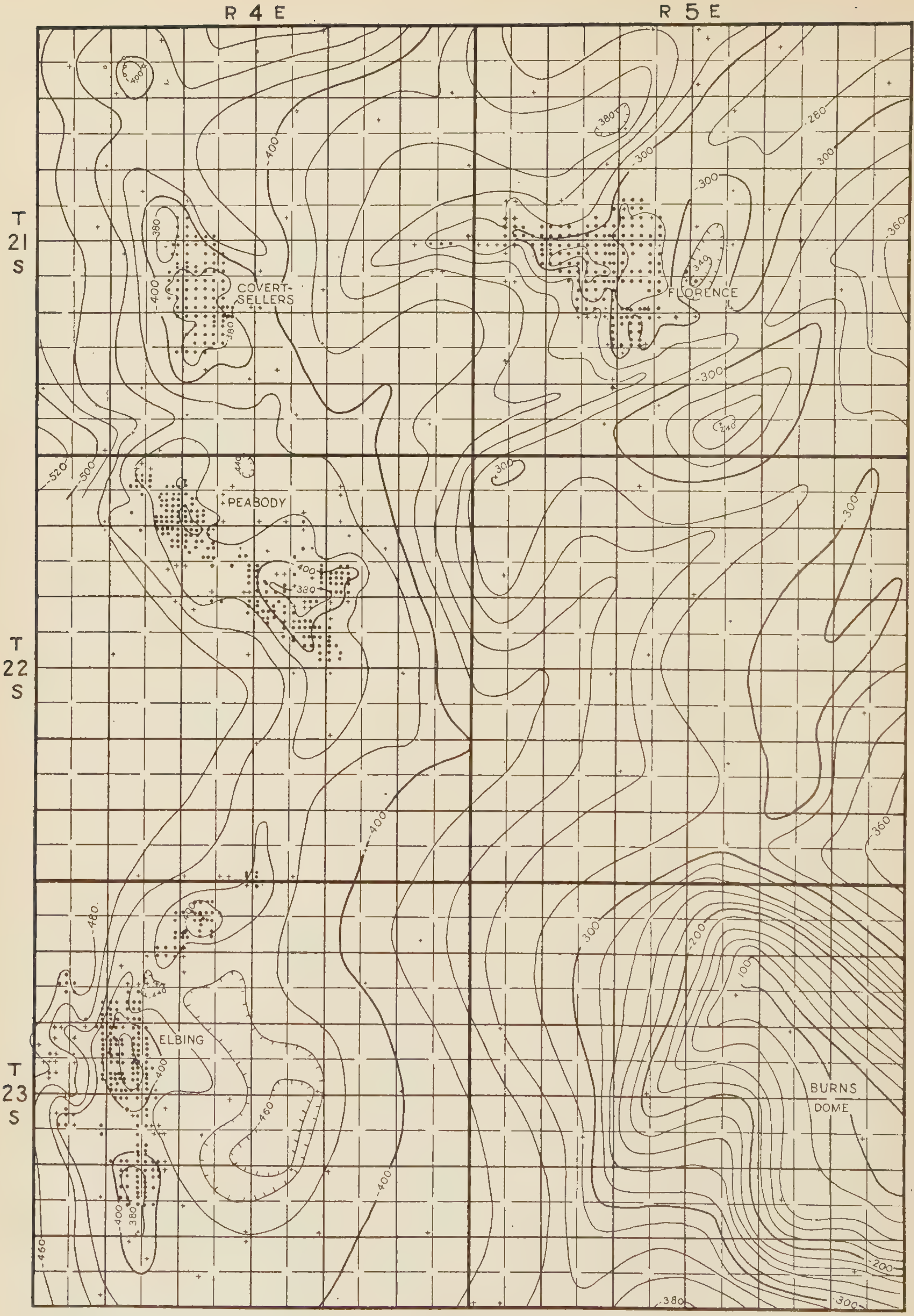


FIG. 2.—Subsurface structure on the Lansing formation. Contour interval, 20 feet. Scale, one township approximately 6 miles square.

FIG. 3.—Subsurface structure on the Ordovician producing horizon. Contour interval, 20 feet. Scale, one township approximately 6 miles square.

Ordovician beds after the uplift of the mountains and to lack of deposition of the lower Pennsylvanian when the structures stood as hills in the advancing Pennsylvanian sea. On the largest structures none, and on the others only part, of the Cherokee (lowermost Pennsylvanian in Kansas) as known in adjacent areas was deposited.

The smaller folds on the west flank of the Nemaha Mountains are contemporaneous with the larger folds of the ridge. Their surface expressions are due to the same causes as those which produced the surface expressions of the larger folds. The difference in structure between the surface and subsurface beds exists for the flank folds as for those of the main ridge.

Generally, on the flank and ridge folds the highest points of the surface folds overlie the highest points of the buried hills. Also, sharp surface dips become sharper subsurface dips.

Until recently the writer has been of the opinion that the theory of differential settling of shales in the horizons covering the buried hills was the only logical explanation of the surface structures overlying them.

Recently observed evidence has convinced him that other forces and factors enter into the formation of these folds. The following facts must be considered. These folds are similar to the El Dorado anticline. The El Dorado anticline is an anticlinal buried hill. With few exceptions the surface structures are directly superimposed upon similar but steeper subsurface folds. The re-entrant synclines along the east flank of the Nemaha Mountains can not readily be accounted for by theories of recurrent folding. No faults are found on the surface. Quantitatively the theory of differential settling does not seem sufficient to account for these structures.

Bearing these facts in mind, the writer is of the opinion that these surface structures are formed through a combination of differential settling and depositional dip of the Pennsylvanian and Permian strata over anticlinal buried hills.

It is also possible that some slight recurrent folding may have occurred, but in the opinion of the writer there is insufficient evidence of such folding to justify the belief that all surface folds are so formed. Furthermore, this theory can not account for the re-entrant synclines found along the east flank of the Nemaha Mountains in the northern part of Kansas.

FAULTING

There is no surface faulting in this region. Subsurface faulting is probably confined to the east face of the Nemaha Mountains. In the

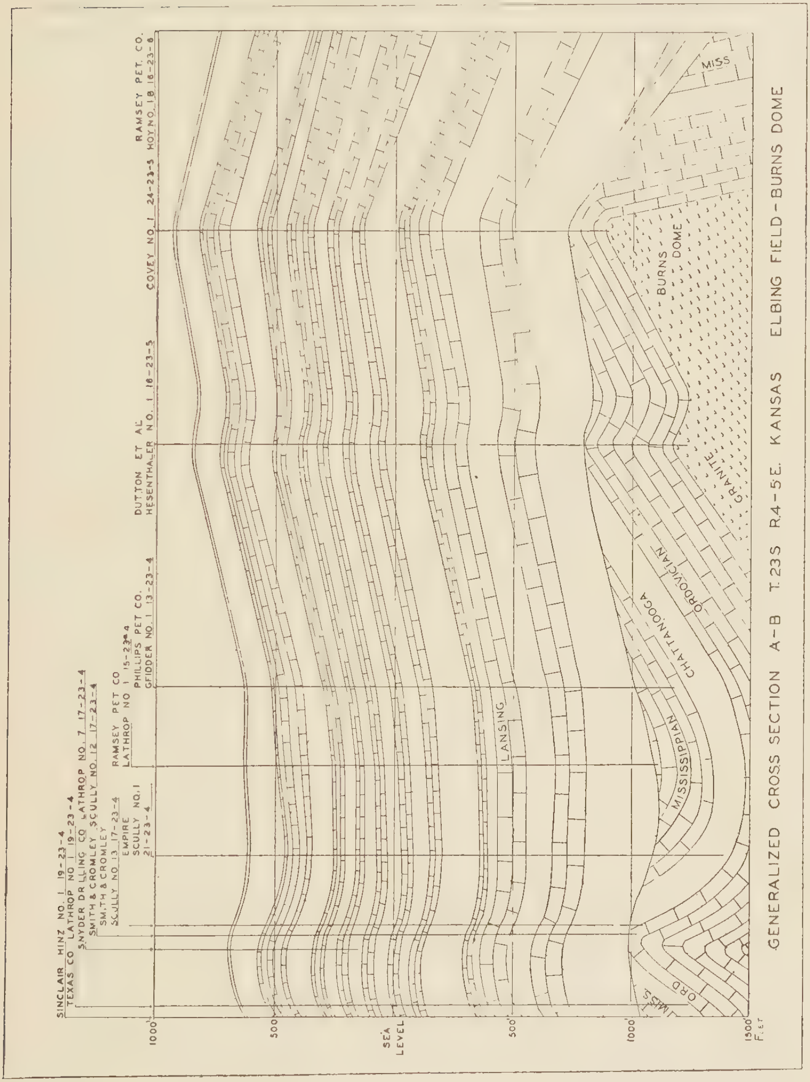


FIG. 4.—Generalized cross section *A–B*, T. 23 S, R. 4–5 E., Kansas, Elbing field, Burns dome. There is no evidence of the conformable relation between the base of the Ordovician and the eroded surface of the granite.

opinion of the writer, the Nemaha Mountains consisted of a long fault scarp extending generally northeast and southwest across the state of Kansas and well into Oklahoma and Nebraska. This scarp was subjected to much erosion; and before it was completely covered by Pennsylvanian sediments, it consisted of many peaks and re-entrant valleys, such as one might expect under such conditions. This must have been a normal fault with the downthrow on the east; but though normal, the area west of the fault seems to have been uplifted rather than that on the east depressed. This seems to be demonstrated by the fact that east of the fault the complete Kansas section is present, whereas, on the west, one must go a considerable distance before it is found.

RESERVOIR ROCKS

The principal producing horizon in this territory is the erosion surface of the Ordovician. This zone consists of a siliceous limestone which is very porous. In many places it is directly overlain by a brown shale of a few feet in thickness. Since the drill goes directly from this brown shale into the "oil sand," and generally finds no hard cap-rock, it is the opinion of the writer that the color of this shale may well be due to the presence of oil directly beneath it. The writer does not know whether or not this shale is found where there is no oil.

SOURCE ROCKS

The source rocks seem to be in the Cherokee and Chattanooga shale section which rests unconformably on the producing horizon down the flanks of the anticlines.[1]

RELATION OF ACCUMULATION TO STRUCTURE

In this area the accumulation of oil is very definitely related to structure. Only the anticlinal hills have produced commercial oil, and these have done so prolifically. In the opinion of the writer this oil has originated from its source in the Cherokee and Chattanooga shales along the west flank of the ridge and has migrated up the slope of the erosion surface eastward until it has been trapped on the tops of these buried hills of pre-Pennsylvanian rocks.

To support this statement one must go well into the theories of the migration of oil. Since the organic theory of the origin of oil is generally accepted, the writer will make no assertions along this line. Since the Cherokee and Chattanooga shales have been well established in both

[1] Henry Ley, "Granite Ridge in Kansas," *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), pp. 95–96.

Oklahoma and Kansas as sources of oil, no further attempts will be made to demonstrate these as such in this instance.

Regarding the accumulation of oil, there are but four possibilities. It originated in the place from which it is produced; it migrated there either laterally or vertically, or by a combination of both lateral and vertical migrations.

Consider the first possibility, that it originated in its present position. In this area no oil is found beyond a few feet below the top of the "pay." The "pay" is so prolific on the tops of the hills that it is impossible for organic remains in these few feet of sediments to be so plentiful as to account for the oil recovered.

Considering the third possibility, that the oil migrated vertically, we must presuppose joints or fractures across the bedding planes of the rocks through which oil may move. Such joints would have been the result of stresses and strains during folding. In this instance, the higher beds being deformed by differential settling, there should be a minimum of jointing as compared with anticlines formed by lateral movements. Furthermore, if this vertical migration were downward, the accumulation should take place at the bottom of a porous horizon. If upward, the logical method, it should be at the top of the reservoir. The oil is, of course, at the top of the reservoir rocks. But, if vertical migration were in force, one should find traces of oil in the beds above or below the "pay." No such traces have been found.

As to a combination of lateral and vertical migration in this area, the same objections apply as to purely vertical migration.

The other possibility, lateral migration, is the only one that fits this area. We have known lateral passageways, the bedding planes of the rocks, and the porous erosion surface of the producing horizon. We have known adequate source rocks down the flanks of the anticlines. We have known anticlinal accumulation and no recognized reason for such accumulation unless the oil has moved laterally.

In so far as the movement up or down the dip is concerned, the writer offers the following data. The more prolific production in this area lies either on the top or along the west flank of the hills. The production extends farther down the slope on the west flank than on the east. East of the Elbing field is the Burns dome. This dome is much higher than the Elbing anticline. Over most of it the Cherokee has never been deposited. Between the field and this dome there is a very limited quantity of possible source rocks. West of all these fields there are untold areas of source rocks.

Taking all the foregoing facts into consideration, the writer believes himself justified in expressing the opinion that in this area the oil has originated in the Cherokee and Chattanooga shales, along the western flanks of these buried hills; that it has migrated laterally through these shales, from the west and up the slope until it has come into contact with the erosion surface of these buried hills. Thence it has moved toward the tops of these hills until it was trapped.

As to the distance covered in this migration, it is impossible to secure any facts on which to base any conclusion. In the opinion of the writer, if it be admitted that oil will travel any distance whatsoever, then no limit can be placed on the distance of its migration, provided that there be sufficient means for moving it and nothing to obstruct its passage.

OIL AND GAS

The average gravity of oil in these fields is about 32° Bé. There is no gas produced in the Ordovician producing zone. Small quantities of gas have been found in the Pennsylvanian series, but very little is of commercial value. In a few places oil has been produced in commercial quantities from sands in the Pennsylvanian, but this production is so limited that it will be given little attention in this paper.

A few wells in this territory have produced naturally from the Ordovician. The vast majority had to be pumped. Those that produced naturally did so with a uniform flow, with no bursts, and with but little daily variation. The pressure behind this flow was purely hydrostatic.

As the fields became more developed, the water problems became more acute. The water line not only encroached more and more toward the tops of the hills, but each well produced an increasing quantity of water. Many methods were devised to handle this tremendous quantity of fluid. The problem was really acute. As there was but a small percentage of oil in the fluid lifted, the lifting cost had to be at a minimum. The combination of very long-stroke pumps, some of them with a roller drum instead of a beam, and 3-inch tubing seemed to give the most satisfaction.

Abandonment, as in other fields, occurred when the cost of production approached the value of the recovered product. The present production of the entire area is small. This does not mean that these were unprofitable fields. On the contrary, they were intensely profitable. The tremendous flush production paid for the development not long after completion, leaving the later production as clear profit.

Another feature of this production is that, owing to the porosity of

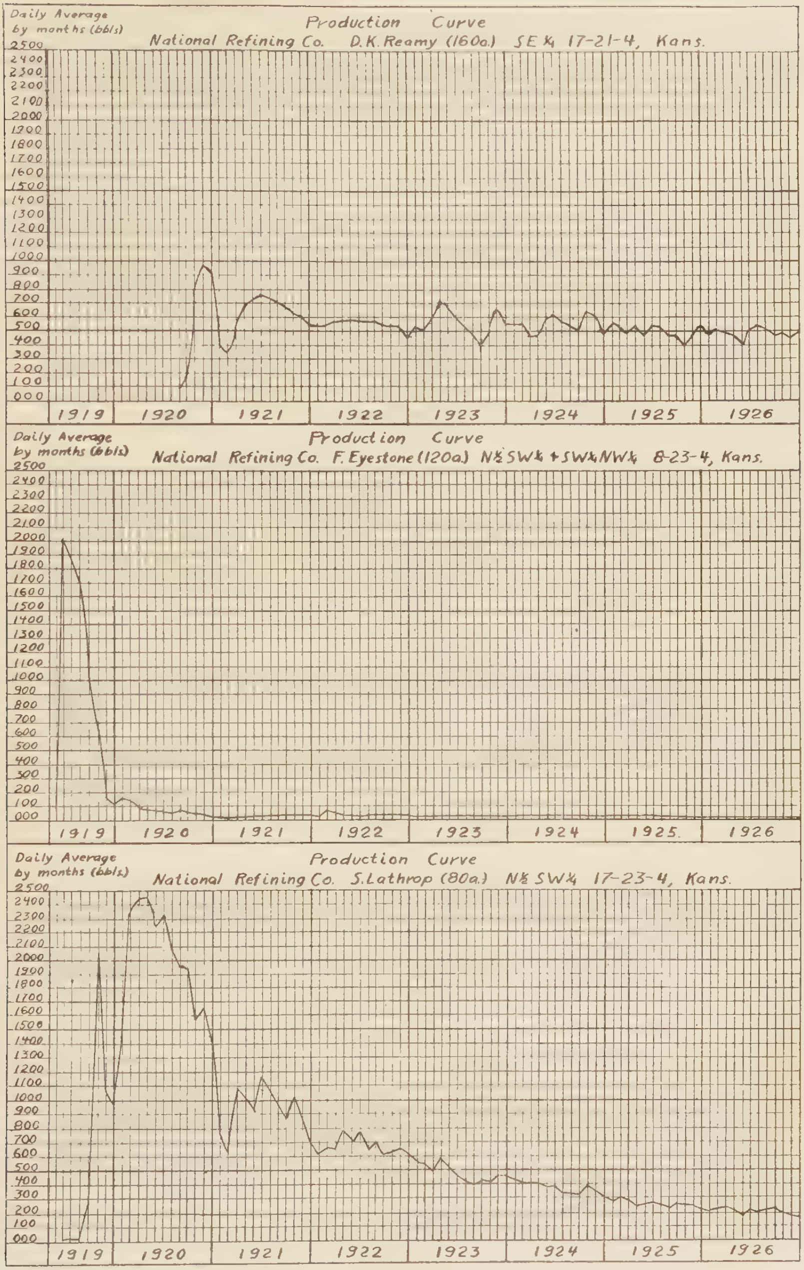


FIG. 5.—Production curves.

the "sand," the encroaching waters sweep most of the oil before them, thus attaining an ultimate recovery much more closely approximating 100 per cent of the accumulated oil than is possible in any less porous "sand" field.

PRODUCTION FIGURES

Owing to the fact that these fields were brought in several years ago, and that production figures of that age are difficult to obtain, the writer has had considerable difficulty in obtaining any accurate production figures. However, he submits curves of three leases in this territory which are based on accurate records (Fig. 5). Of these three curves submitted there is such a lack of similarity that no effort is made to suggest that any one of them is a type curve of this area.

SUMMARY

In this paper the following conclusions have been reached.

The principal producing horizon is the unconformable contact between the Ordovician and overlying sediments.

The surface folds, with minor exceptions, consistently overlie the buried hills of pre-Pennsylvanian rocks.

The surface folds are due to differential settling and depositional dip over these buried hills.

The petroleum accumulation has been due to lateral migration.

The porosity of the reservoir rock and the encroaching waters have caused an extremely high percentage of ultimate recovery.

BIBLIOGRAPHY

Eliot Blackwelder, "Origin of the Central Kansas Oil Domes," *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 4 (1920), pp. 89–94.

A. E. Fath, "Geology of the El Dorado Oil and Gas Field," *Geol. Survey of Kansas, Bull. 7* (1921).

Erasmus Haworth, "Crystalline Rocks of Kansas," *ibid., Bull. 2* (1915).

Henry Ley, "Granite Ridge in Kansas," *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), pp. 95–96.

Raymond C. Moore, "Geologic History of the Crystalline Rocks of Kansas," *ibid.*, Vol. 2 (1918), pp. 102–13.

RELATION OF PRODUCTION TO STRUCTURE IN FIVE OIL AND GAS FIELDS OF THE KENTUCKY EASTERN COAL FIELD[1]

L. E. FISKE[2]
Bartlesville, Oklahoma

ABSTRACT

In this paper are described the structure and related production in five oil and gas fields of the eastern coal field of Kentucky, namely (1) the Lee-Estill-Powell oil field, (2) the Campton oil field, (3) the Owlsey County gas field, (4) the Clay County gas field, and (5) the Elliott County oil field. The producing beds are Pennsylvanian, Mississippian, Devonian, and Silurian in age, most important being the Corniferous limestone of the Devonian. The major structural features of the general area are the Cincinnati arch and Paint Creek uplift, whose axes extend north and south, and the Pine Mountain and the Irvine-Paint Creek faults and uplifts, whose axes extend east and west. These two systems of folding are dominant features in eastern Kentucky. The Cincinnati arch has had a marked effect on both structure and stratigraphy. It was probably a positive element throughout the time of deposition of the formations in these fields. Formations increase in thickness with distance from the arch, and minor folds parallel the arch. Subsequent folding and faulting with east and west axes were the result of pressure from the south. Production is related to structure only in a general way; the porosity of the sands and limestones seems to be the controlling factor for oil and gas accumulation. Several wells have been drilled in the Elliott County oil field proving the crest of the main fold to be dry, probably because of unfavorable sand conditions. An interesting feature of the map of the eastern coal field is the relation of the oil and gas production and the isocarbs to the major uplifts and faults. The Irvine sand pools, which produce 60 per cent of the oil in the state, lie along the flank of the Irvine-Paint Creek uplift, paralleling the Irvine-Paint Creek fault. The Wier pools, which produce 30 per cent of the state's oil, lie along the axis of the Paint Creek uplift. This close relation of production to uplift bears out the theory that oil was formed during, and as a result of, folding, rather than that it had been formed prior to the fold and had subsequently migrated into it. Folding seems essential to oil accumulation in eastern Kentucky, but the degree of folding must not pass beyond a certain point or the hydrocarbons will be changed to gas. The most favorable formations for producing oil are stratigraphically high, geologically young, and moderately folded. The probability of finding many new oil fields of importance is not large.

INTRODUCTION

The author attempts to show in this paper the relation of oil and gas production to folding in five oil fields of the eastern coal field of Kentucky, the Lee-Estill-Powell oil field, the Campton oil field, the Owsley County gas field, the Clay County gas field, and the Elliott County oil field.

[1] Presented before the Association at the Tulsa meeting, March, 1927. Reprinted from *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 5 (May, 1927), pp. 477–92.

[2] Wiser Oil Company. Introduced by Frank R. Clark.

The location of the eastern Kentucky coal field is shown in Figure 1, and the locations of the oil and gas fields are shown in Figure 2.

The field work on which the structure maps in this report are based was done during the years 1921 and 1922 by the members of the geological department of Petroleum Exploration, Inc., Lexington, Kentucky.

Correlation of beds is largely from the publications of the Kentucky Geological Survey.

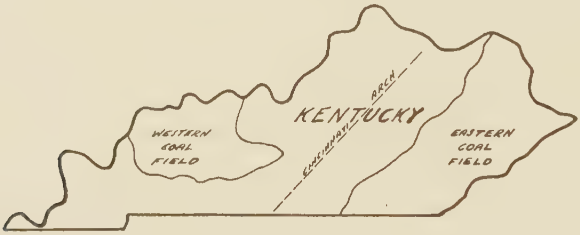


FIG. 1.—Outline map of Kentucky, showing the location of the eastern coal field.

STRATIGRAPHY

The succession of beds encountered in eastern Kentucky is shown graphically in the cross section, Figure 3. All of these beds crop out between the axis of the Cincinnati arch and the Virginia state line. In descending order, they are the upper Pottsville coals, shales, and sandstones, and the lower Pottsville sandstone-conglomerate and coals, of Pennsylvanian age; the Mauch Chunk shales, sands, and limestones, the St. Louis limestone, and the Waverly shales and sandstones, of the Mississippian; the Chattanooga black shale and Corniferous limestone of the Devonian; the Niagara shales and limestone of the Silurian; and the Richmond shales and Lexington limestone of the Ordovician. In this columnar section the beds producing oil or gas in the eastern coal field are shown in Table I.

TABLE I

BEDS PRODUCING OIL OR GAS IN THE EASTERN COAL FIELD

Age	Formation	Bed
Pennsylvanian	Pottsville conglomerate	Salt sands
Mississippian	Mauch Chunk	Maxon sand
Mississippian	Waverly	Wier and Berea sands
Devonian	Corniferous	Corniferous limestone
Silurian	Niagara	Clinton sand

In addition, some gas is encountered in the St. Louis limestone and the Big Injun sand at its base, of Mississippian age.

STRUCTURE

The major folds and faults of the eastern coal field are shown in Figures 1 and 2, namely, the Cincinnati arch, the Pine Mountain fault and uplift, the Irvine-Paint Creek fault and uplift, and the Paint Creek uplift. It should be noticed that the axes of the Cincinnati arch and the Paint Creek uplift extend approximately north and south, and that the Pine Mountain and Irvine-Paint Creek faults and uplifts trend approximately east and west. These two systems of folding are apparent in all the structural folds of eastern Kentucky. Each fold has a minor axis at right angles to the major axis.

The Cincinnati arch has had a marked effect not only on the structure of the eastern coal field but on the stratigraphy as well. This arch seems to have been a positive element during all the times here under discussion, as shown by the thickening of beds away from the arch (Fig. 3). The history of this arch as interpreted from these beds is interesting.

ORDOVICIAN, SILURIAN, AND DEVONIAN TIMES

There is evidence that the arch existed soon after the close of Ordovician time, as the Silurian beds show a rapid thickening away from the axis of the arch, and also a change from shale and sand, shallow-water deposits, to limestone, a deep-water deposit. The Corniferous limestone shows the same thickening, but to a lesser degree, showing that the rise during this period was small. The Devonian black shale, however, shows a change from 100 feet of thickness in Powell County to 700 feet in Knott County, indicating a considerable rise either just prior to, or during, the deposition of the black shale in the shallow waters of the Devonian seas. It is also possible that the uplift occurred after the deposition of the shale and that erosion removed the greater part from the crest. The general history, however, indicates a slow continuous rise of the arch.

MISSISSIPPIAN TIME

There seems to have been little or no movement of the arch during Mississippian time. The Berea sandstone was laid down on the shores of the early Waverly seas on the top of the Devonian. It extended almost to the eastern edge of Breathitt County. The deposition of the alternating shales and sandstones of the Waverly then took place, indicating an oscillating shore line. At the close of the Waverly a general submergence occurred and the St. Louis limestone was deposited. Both the Waverly and the St. Louis show a nearly even thickness across the region, indicating no important movement of the arch. Next in order, the Mauch Chunk

beds were deposited upon the St. Louis. They indicate a period of alternating shallow water, deep water, and shore conditions. It was at the close of the Mauch Chunk that the principal uplift of the arch took place, and, judged from the basin produced, which was later filled with Pottsville conglomerate, this rise must have been nearly a thousand feet. A

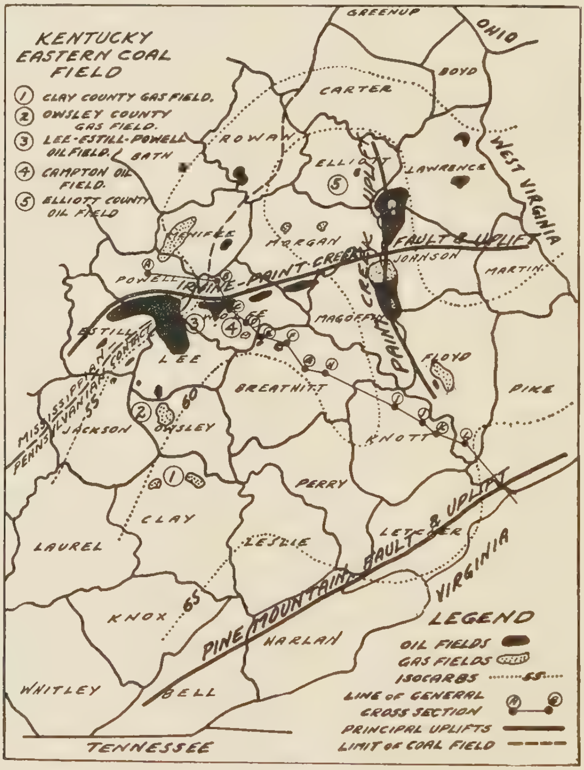


Fig. 2.—Map of Kentucky eastern coal field.

period of erosion then ensued which removed the Mauch Chunk from the arch down the flank as far as the eastern edge of Breathitt County, and eroded part of the St. Louis as well.

PENNSYLVANIAN TIME

The erosion of the Mauch Chunk from the crest of the arch and the removal at the same time of material from the Appalachian highland on the east furnished sediment for the Pottsville rivers and shallow seas to fill up the basin between these highlands. As stated before, this lower

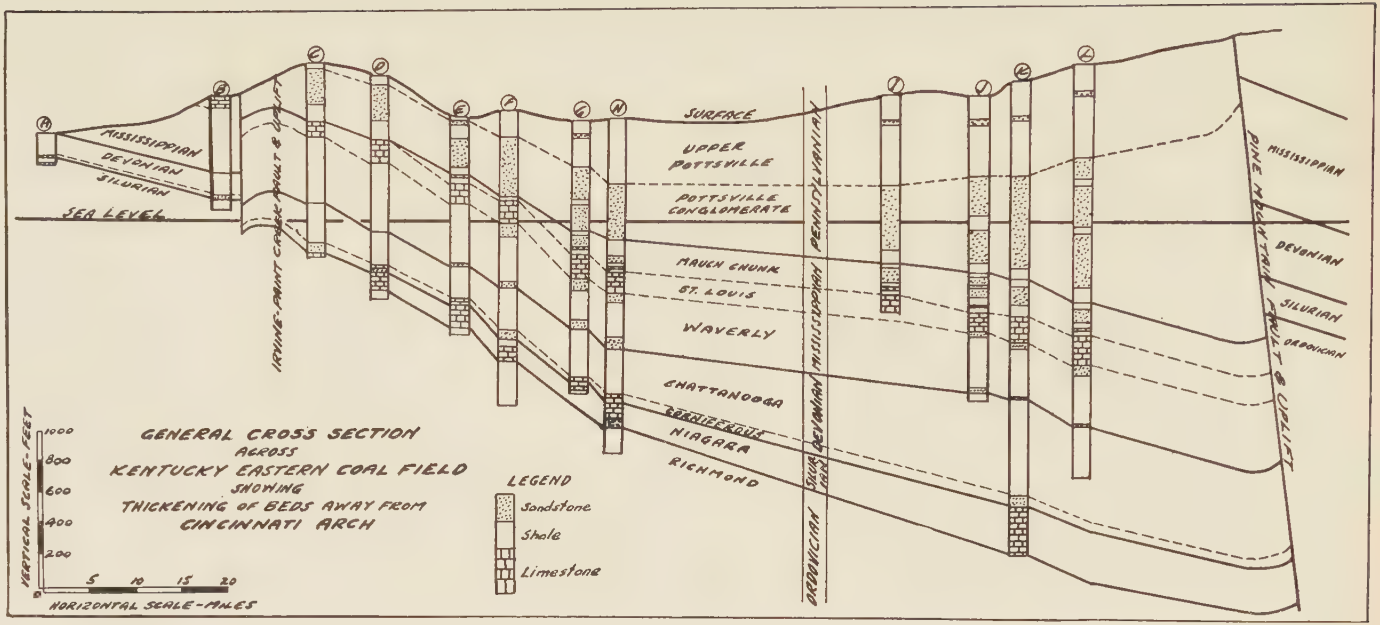

GENERAL CROSS SECTION
ACROSS
KENTUCKY EASTERN COAL FIELD
SHOWING
THICKENING OF BEDS AWAY FROM
CINCINNATI ARCH
LEGEND
Sandstone
Shale
Limestone
VERTICAL SCALE-FEET
1000
800
600
400
200
HORIZONTAL SCALE-MILES
5
10
15
20
SEA LEVEL
MISSISSIPPIAN
DEVONIAN
SILURIAN
IRVINE-PAINT CREEK FAULT & UPLIFT
SURFACE
UPPER POTTSVILLE
POTTSVILLE CONGLOMERATE
MAUCH CHUNK
ST. LOUIS
WAVERLY
CHATTANOOGA
CORNIFEROUS
NIAGARA
RICHMOND
PENNSYLVANIAN
MISSISSIPPIAN
DEVONIAN
SILURIAN
ORDOVICIAN
PINE MOUNTAIN FAULT & UPLIFT
MISSISSIPPIAN
DEVONIAN
SILURIAN
ORDOVICIAN

FIG. 3

Pottsville formation is principally sandstone-conglomerate, with only a few coals and breaks of shale, indicating terrestrial conditions in the main; river and shore sands; shallow-water shales; and, here and there, swamps forming coal. This condition continued until 1,200 feet of this material had been deposited near the southern boundary of Kentucky and at least 100 feet near the crest of the arch, again producing flat topography. That the material at least for the upper part of the conglomerate came from the east is shown by the uniform angle of cross-bedding in the formation, the inclination being about 45° W. The upper Pottsville beds were next deposited. They represent conditions analogous to those during deposition of the conglomerate, except that swamp conditions and periods of shallow submergence predominate, with stream and shore deposits occurring only at intervals, producing a series of coals and shales interspersed with sandstones.

FINAL RISE OF THE ARCH

After deposition of the Pottsville sediments, at some period which cannot be accurately determined, the arch was again uplifted, tilting the Pottsville beds into their present inclination away from the axis (dip, 40 feet per mile), and increasing the inclination of all the lower beds. It is probable that at this same time was formed the series of north-south minor folds across the eastern coal field, of which folds the Paint Creek uplift in Magoffin and Johnson counties is the largest. The axes of these many minor folds are parallel to the axis of the arch. It is probable that these disturbances took place not long after the deposition of the upper Pottsville.

PINE MOUNTAIN FAULT AND IRVINE-PAINT CREEK FAULT

The disturbance which was responsible for the Pine Mountain and Irvine-Paint Creek faults was general from Pennsylvania as far west as Missouri, and, it is believed, occurred in Tertiary time. The faulting was preceded by a great pressure from the south, causing anticlinal folding with east-west axes. The overthrusting of the Pine Mountain anticline and the formation of the Irvine-Paint Creek fault (and on the north, the Sandy Hook fault) released this pressure. In areas where these Tertiary anticlinal axes cross the axes of the older north-south folds, formed with the last rise of the arch, doming has resulted in many places.

The nature of the Pine Mountain fault can be seen from the graphic cross section. This structural feature began as a large anticlinal fold, which broke at the top and terminated in an overthrust fault having a throw of more than 2,000 feet.

The Irvine-Paint Creek fault has a vertical displacement of 200 feet. Faulting occurred low on the north flank of an anticlinal fold, resulting in a greatly increased dip of this flank of the anticline.

LEE-ESTILL-POWELL OIL FIELD

The stratigraphy and structure of the Lee-Estill-Powell field is shown by Figures 4, 5, and 6. This field produces an oil of about 38° Bé. from the Corniferous limestone at 1,000 feet. Production is from porous lenses in a magnesian limestone. There are three well-defined pay horizons, in about 100 feet of formation. The lower part may belong to the Silurian, though the division cannot be determined from well logs.

The field lies along the south flank of the Irvine-Paint Creek uplift. The field at Estill Furnace, which was drilled in 1915, lies at the south and on the upthrow side of a block fault. On the east, the Estill Furnace fault, which represents a break at the crest of the anticline, disappears; and the anticline assumes a normal shape, with a fault on the north flank. Scattered production occurs along the crest and down the south flank, but the prolific part of the field is in Lee County, near the junction of the county lines. Drilling here began in 1917. The best wells produce from the third "pay," the first and second "pays" in many places bearing water.

A comparison of the surface and subsurface folding may be made from Figures 4 and 5. The folds in the St. Louis are seen to be reflected in the Corniferous, but there are minor folds in the Corniferous not found in the surface beds. These minor folds suggest an old eroded topography of the Corniferous limestone rather than structural deformation.

The Lee-Estill-Powell field has produced a large part of Kentucky's petroleum since 1916. Petroleum Exploration's properties in this field have produced to date an average of 3,500 barrels per acre and, it is estimated, will show an ultimate production of 5,000 barrels per acre.

The conclusion to be drawn as to the relation of production to folding in this field is that, while production is undoubtedly associated with major folding and faulting, its location is entirely controlled by the character of the pay horizon, production occurring where porous lenses are found in the limestone.

CAMPTON OIL FIELD

The Campton field also lies along the Irvine-Paint Creek uplift, about 10 miles east of the Lee-Estill-Powell field. This field was drilled in 1905. Production is from the Corniferous limestone at 1,200 feet. The two axes of folding mentioned before are very apparent in this field (Fig. 7). The Irvine-Paint Creek fault and anticline trend east and west, while

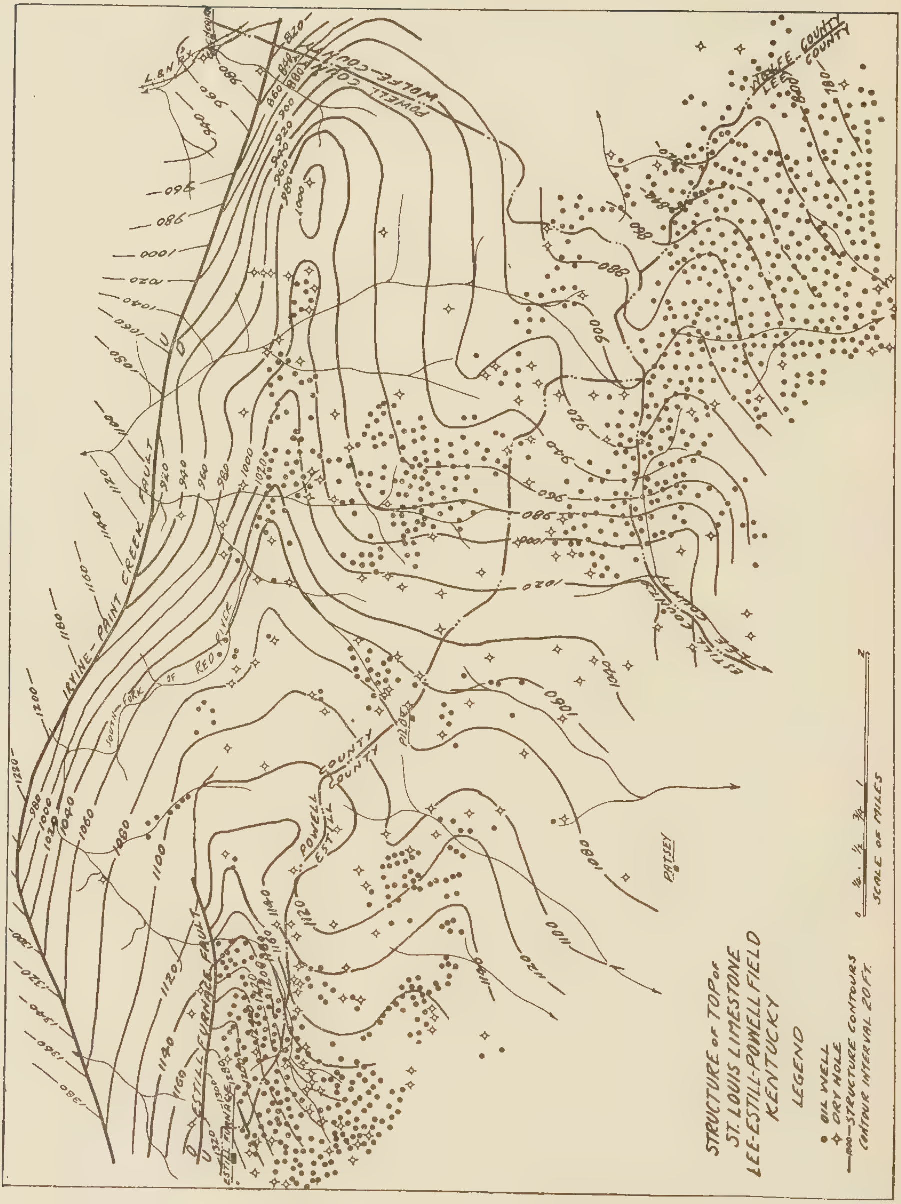

STRUCTURE OF TOP OF
ST. LOUIS LIMESTONE
LEE-ESTILL-POWELL FIELD
KENTUCKY
LEGEND
OIL WELL
DRY HOLE
STRUCTURE CONTOURS
CONTOUR INTERVAL 20 FT.
SCALE OF MILES
IRVINE-PAINT CREEK FAULT
ESTILL FURNACE FAULT
SOUTH FORK OF RED RIVER
POWELL COUNTY
ESTILL COUNTY
WOLFE COUNTY
LEE COUNTY
PATSEY
PILOT
ESTILL FURNACE
L. & N. R.R.

FIG. 4

the Stillwater fault and the minor axis of folding at Campton trend north and south. The crest of the main anticline at Campton is dry, production occurring well down on the south flank. Production also extends southward along the crest of the minor fold, giving the field a shoestring appearance. On the east side of the Stillwater fault, production occurs along the crest of the main fold, after an interval of dry territory. The con-

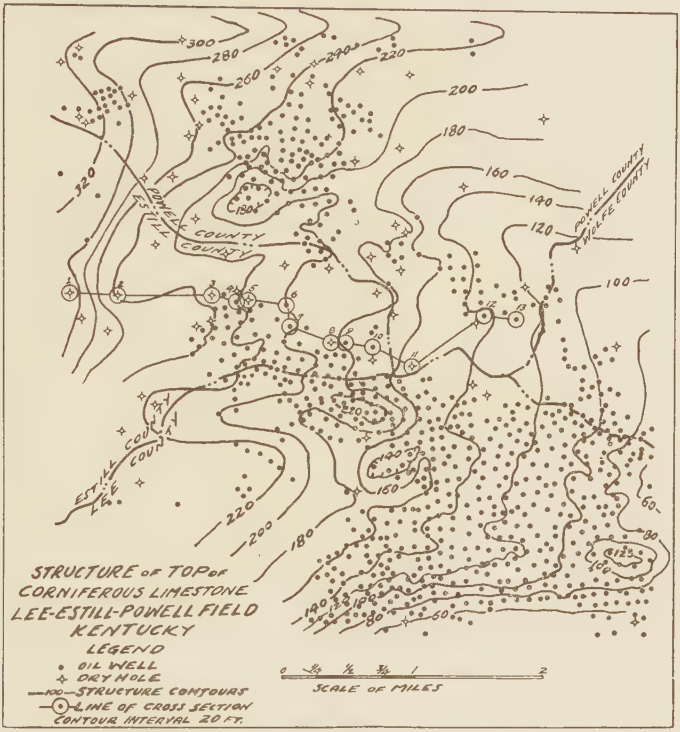


FIG. 5

clusion must again be drawn that the principal control of production in this field is the local character of the Corniferous limestone.

OWSLEY COUNTY GAS FIELD

The Owsley County gas field lies about 20 miles south of the Lee-Estill-Powell County oil field. The gas field as now outlined covers approximately 5 square miles and has about 30 scattered producing wells. The wells range in size from 1,000,000 to 3,000,000 cubic feet, open-flow capacity, at 300 pounds initial rock pressure. The gas was utilized for two

years in a carbon-black plant, and on the basis of the pressure decline due to this production, the potential reserves of the field are placed at about 20 billion cubic feet. The gas is not being marketed at present, though it is probable that it will be piped to the city of Lexington, 60 miles northwest.

North of the gas field, in Lee County, with dry territory intervening, there is a small oil field. Gas production is from the top of the Corniferous limestone at 1,400 feet, and the oil comes from the base of the same formation.

The structure of the producing horizon is shown in Figure 8. Although there is some doming and minor folding, and a suggestion of a terrace at the gas field, there is no major fold, such as found at the other fields described; and the folding does not account for the localization of production. Production here seems to be controlled entirely by favorable conditions of porosity in the reservoir rocks.

CLAY COUNTY GAS FIELD

Twelve miles south of the Owsley County field there is a gas field which has not been fully defined, but in which enough wells have been drilled to demonstrate that it is of commercial proportions. Wells are of about the same size and pressure as in the Owsley County field and produce from the same horizon at a depth of 1,600 feet. The territory which seems to be proved at present consists of about 4 square miles just south of the town of Oneida.

By referring to Figure 9, it can be seen that this gas field is associated with a major anticline showing the characteristic major and minor axes at right angles to each other. Several good gas wells have been drilled on the north flank of the fold, near Burning Springs; but the commercial part of the field seems to be along the south flank of the minor fold, south of Oneida.

Production in this field seems to be associated with major folding but localized by the character of the producing horizon.

ELLIOTT COUNTY OIL FIELD

At the north end of the Paint Creek uplift there is a small oil field which is of little importance commercially but which is interesting structurally. The structure adjacent to this field is shown in Figure 10.

The folding consists of a major axis and fault parallel to the Irvine-Paint Creek fault and a minor axis parallel to the Paint Creek uplift. Several wells have been drilled which have proved that the crest of the

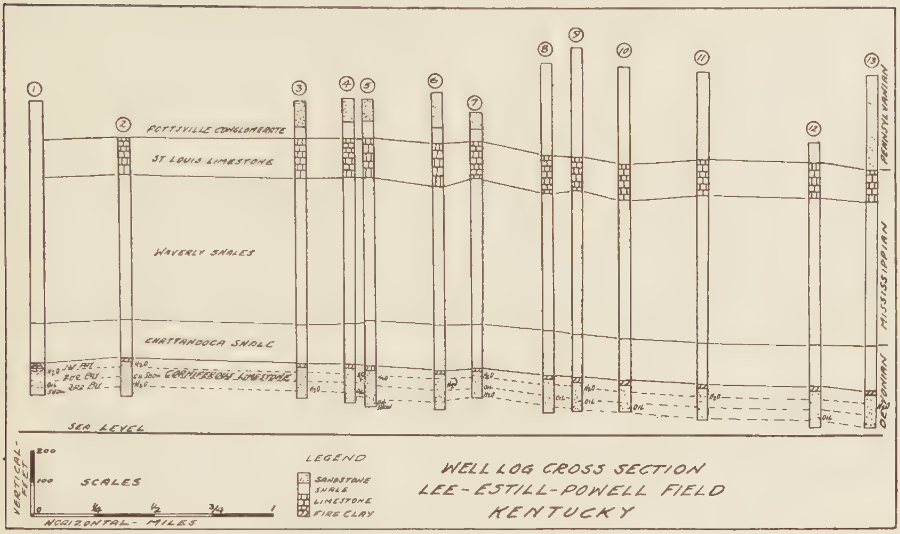


FIG. 6

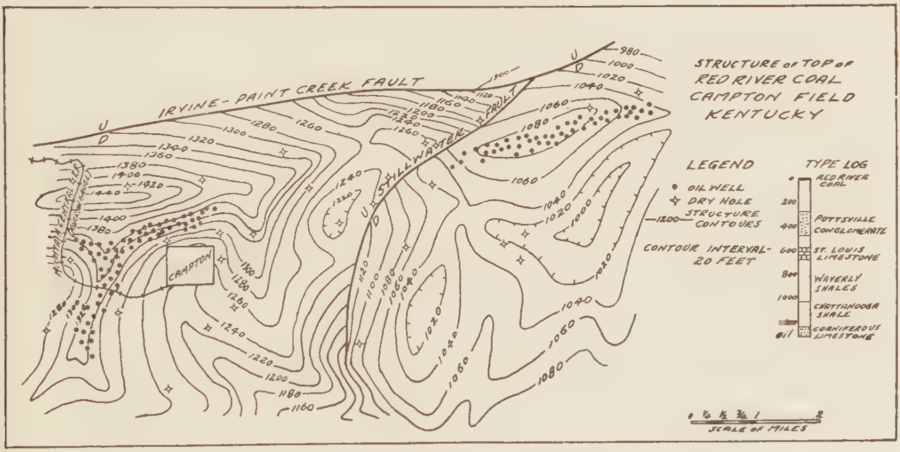


FIG. 7.—Map showing structure of the top of the Red River coal, Campton field, Kentucky.

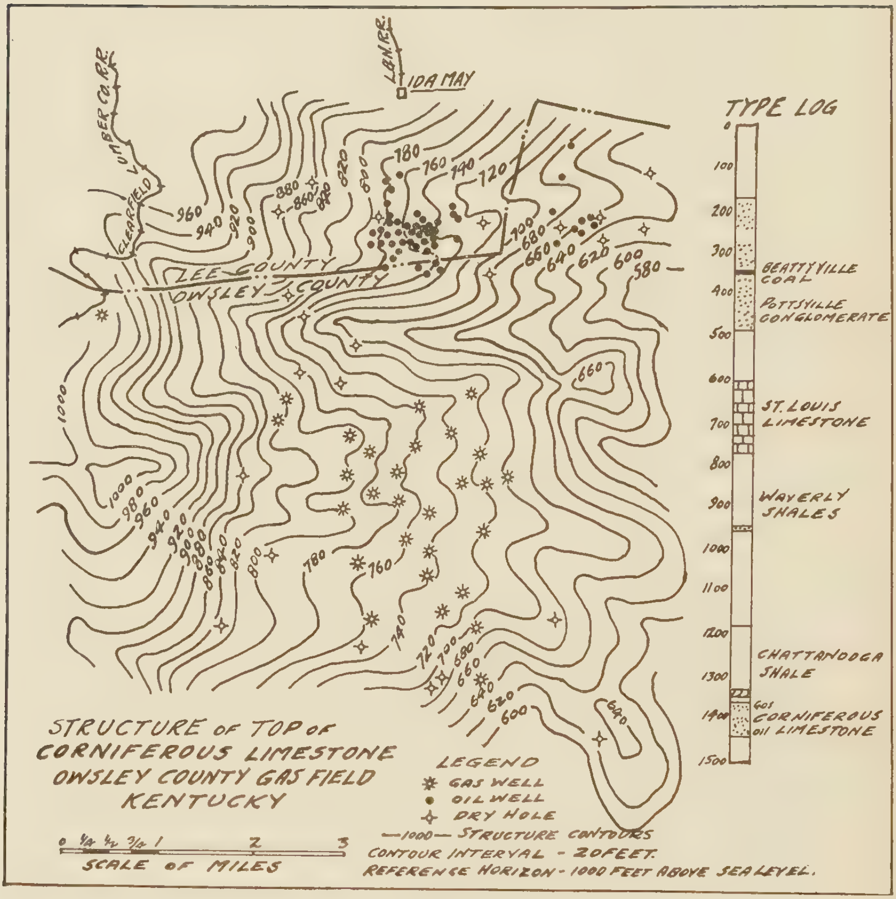

TYPE LOG
BEATTYVILLE COAL
POTTSVILLE CONGLOMERATE
ST. LOUIS LIMESTONE
WAVERLY SHALES
CHATTANOOGA SHALE
CORNIFEROUS OIL LIMESTONE
IDA MAY
L&N RR.
CLEARFIELD LUMBER CO. R.R.
LEE COUNTY
OWSLEY COUNTY
STRUCTURE OF TOP OF CORNIFEROUS LIMESTONE
OWSLEY COUNTY GAS FIELD
KENTUCKY
LEGEND
GAS WELL
OIL WELL
DRY HOLE
1000 STRUCTURE CONTOURS
CONTOUR INTERVAL - 20 FEET.
REFERENCE HORIZON - 1000 FEET ABOVE SEA LEVEL.
SCALE OF MILES

FIG. 8

main fold is dry in all horizons. On the south flank of the minor fold, however, there are some small oil wells in the Wier sand and two gas wells in the Corniferous limestone.

The Elliott County field seems to be one where structural conditions are favorable but where sand conditions are not.

POSSIBILITIES OF THE EASTERN COAL FIELD AS A WHOLE

In studying the possibilities of obtaining new pools of oil and gas in the eastern coal field of Kentucky, reference should be made to Figure 2, which shows the relation of the present known pools of the major structural features and to the percentage of fixed carbon in the exposed Pennsylvanian coals. The theory that a definite relation exists between the percentage of fixed carbon in the coals of an area and the character of any oil and gas deposits was advanced some years ago by David White. This theory has been applied to many of the principal oil and gas fields producing from coal-bearing areas, and has proved well founded.

METHOD OF CONSTRUCTING THE ISOCARB MAP

The contour lines connecting points of equal fixed-carbon content are termed "isocarbs." To establish these lines, analyses from all counties containing commercial coals in eastern Kentucky were collected from state survey reports and from operating coal companies. These analyses were grouped together by areas. Usually the watersheds of streams were taken as the units of area, as it is in this way that state reports are classified, and in addition, all mines are located along some principal drainage line. The percentage of fixed carbon in each analysis was computed on a pure-coal basis (moisture and ash excluded), and the results of each group were averaged and placed at the center of the group. Each percentage value placed on the map was therefore the average of 10 to 100 analyses. It was found necessary to discard all analyses of cannel coal as this grade runs about 20 per cent lower in fixed carbon than the bituminous coals. It was noticed, however, that the cannels showed a progression in fixed-carbon content, in the same direction and of about the same amount as the bituminous coals, and that no cannel existed in the areas of high-carbon bituminous coals.

INTERPRETATION OF THE MAP

It has been found generally true, in applying isocarbs to producing areas, that production below isocarb 55 is principally oil of low or medium gravity, that between isocarbs 55 and 60 production is of medium to high-gravity oil and gas, that between isocarbs 60 and 65 production is prin-

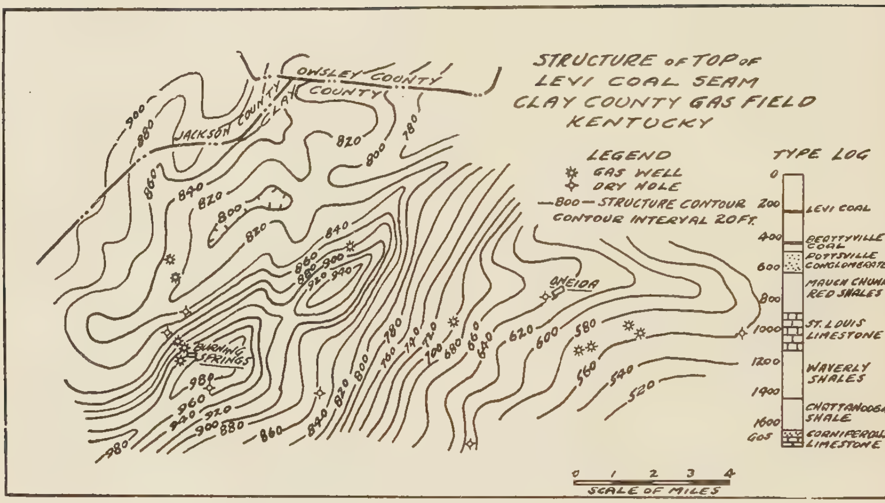


FIG. 9

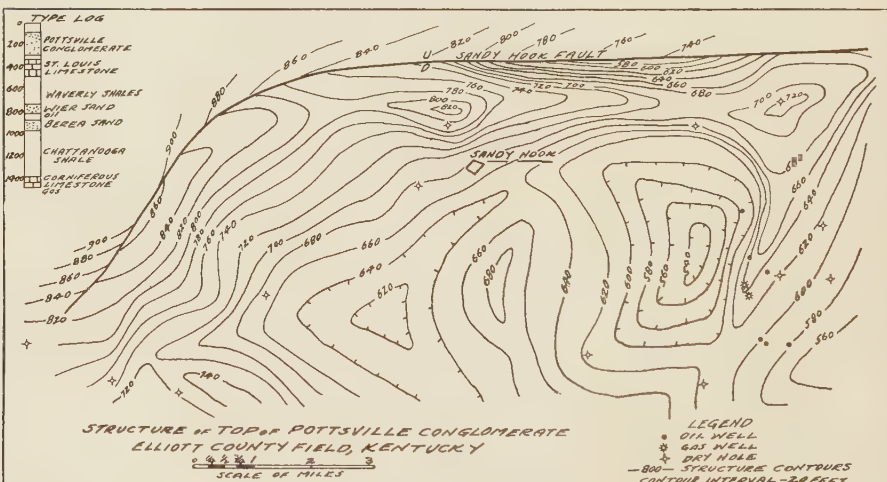


FIG. 10.—Map showing structure of the top of the Pottsville conglomerate, Elliott County field, Kentucky.

cipally of gas or very high-gravity oil in shallow sands, and that above isocarb 65 very little or no commercial production of oil or gas may be expected. A study of the map of eastern Kentucky shows this region to follow these rules. The principal producing oil pools of this part of the state, the Corniferous lime pools of Estill, Lee, Wolfe, and Morgan counties, the Berea pools of Lawrence, and part of the Wier pool of Lawrence and Johnson counties, all lie below isocarb 60, and production is shallow, from a depth of 800 to 1,500 feet. The remainder of the Wier pool in Lawrence and Johnson counties, and the Magoffin County Wier pool, lie just above isocarb 60. This production, however, is a high-gravity oil from a shallow sand, depths ranging from 600 to 1,200 feet. It should also be stated that the big production is in Lawrence County, below isocarb 60, and that the Magoffin County pool, above isocarb 60, produces uniformly small wells from a tightly cemented sand. But one other occurrence of commercial oil is found above isocarb 60, namely, the Bosco pool in Floyd County. This oil has a gravity of 42° to 48° Bé., and is produced from Pottsville sands at a depth of 800 feet. The carbon ratio here is 62, precluding the possibility of any production but a high-gravity oil from a shallow sand such as occurs in this pool. Other commercial occurrences above isocarb 60 are the gas pools of Martin, Johnson, Floyd, and Clay counties. Above isocarb 65 nothing has been found of importance, as is to be expected.

RELATION OF OIL AND GAS PRODUCTION TO MAJOR UPLIFTS

An interesting feature of the map of the eastern coal field is the relation borne by the oil and gas production and by the isocarbs to the major uplifts and faults. It will be noticed that the Irvine sand pools (Estill, Lee, Wolfe, and Morgan counties), which produce about 60 per cent of the oil produced in the state, lie along the flank of the Irvine-Paint Creek uplift, which parallels the Irvine-Paint Creek fault. It will be further noticed that the Wier pools of Lawrence, Johnson, and Magoffin counties (producing 30 per cent) lie along the axis of the Paint Creek uplift. Other production in eastern Kentucky is of very minor importance compared to these pools. The isocarbs are also controlled by the older folding, as shown by the position of isocarb 60, to include the Paint Creek uplift.

The close relation of production to uplift, here mentioned, bears out the theory that oil was formed during, and as the result of, folding, rather than that it had been formed prior to the fold and had subsequently migrated into it. It may be generally stated, therefore, that folding seems essential to the accumulation of oil in eastern Kentucky, but that the

degree of folding must not pass beyond a certain point (which point is first exceeded by the deeper sands) lest the hydrocarbons be changed to gas or lost. The most favorable formations for producing oil are those which are stratigraphically high, geologically young, and moderately folded.

FURTHER CONDITIONS AFFECTING THE ACCUMULATION OF OIL IN EASTERN KENTUCKY

In addition to the general conditions already discussed, the search for oil in eastern Kentucky is further affected by certain local conditions of the producing horizons, which are somewhat different for each of the several horizons.

THE CORNIFEROUS LIME AND CLINTON SANDS

These sands, of Devonian and Silurian age, respectively, belong to horizons geologically old; hence, they can be expected to produce only high up on the side of the Cincinnati arch where they have not been covered by any great depth of succeeding sediments in more recent times. In addition to this condition, the lithologic character of the horizons must be considered in prospecting. Both horizons are essentially impure, porous limestones containing irregular true sand inclusions. Therefore, although they afford good reservoirs where porous enough, the change in porosity is so abrupt in many places that an offset to a producing well may be dry. All the known Corniferous and Clinton (Niagara) pools of the state are lenticular in character. The largest lens is beneath the south end of the Lee-Estill-Powell field, in Lee County. Here a large, highly porous, true sand inclusion in the Corniferous is encountered, which has produced some really remarkable wells. It can be generally stated, regarding the Corniferous and Clinton, that production will occur somewhere upon the flanks of the major folds (generally not on the top, probably because folding here has been more intense and has tightened the sand) and that production will be controlled by structure in so far as the sand continues with even porosity, but that the principal control of production will be the location of the porous streaks in the limestone, or the position of the included sand lenses.

THE WIER SAND

The Wier sand, which ranks next to the Corniferous as a prolific producer of oil in eastern Kentucky, is a true sandstone, very fine-grained, and lenticular in character. It does not extend as a continuous sand any great distance beyond the limits of the Paint Creek uplift. Outside these boundaries, the sand is broken by several beds of shale, and fails to pro-

duce on minor structures surrounding the Paint Creek uplift. Most of the production occurs in the top bed of the Wier, above the first shale break, where this top sand is thick. Where it thins to less than 5 feet, production ceases. Some wells are obtained in the lower Wier, but they are never large. Several explanations may be offered for these conditions. It is possible, because of the fine texture of the sand, that a great thickness of "pay" is required to furnish large production; that it required a major uplift, such as the Paint Creek uplift, to generate the oil; that the source rock is lacking in outlying structures; or that the sand is too tight in outlying areas to form a good reservoir. A careful study of the Wier sand from well logs and sand samples would probably determine the true explanation for the localization of production in this sand.

THE BEREA SAND

The Berea sand is a source of commercial production in Lawrence County, but tests in other localities have been unsuccessful in this horizon. This bed is recognized to be a non-water-bearing, gritty sandstone with great variations in porosity. Production seems to be synclinal in general, but not everywhere. Accumulation is controlled to a great extent by the porosity. This horizon has some possibilities in the northeastern counties, but its spotted character makes it a difficult horizon to prospect. It will produce nothing but gas above isocarb 60, because of its depth above this contour.

POSSIBLE NEW OIL AND GAS TERRITORY OF EASTERN KENTUCKY

It is now possible, by considering the facts brought out, to list the counties of eastern Kentucky according to their possibilities as areas of probable oil production, of probable gas production, or as dry areas.

COUNTIES FAVORABLY LOCATED FOR OIL

In addition to the parts of Estill, Lee, Wolfe, Morgan, Lawrence, Johnson, and Magoffin counties already mentioned as productive, there are several counties which, with the information available at the present time, are not condemned as oil producers. If the Irvine-Paint Creek uplift extends from Estill County west into Jackson and Rockcastle counties, as seems to be the fact, production of oil from lenses in the Corniferous "lime" is quite probable. These two counties, therefore, seem to merit further investigation. Lewis, Greenup, and Boyd counties have possibilities of oil production provided they are crossed by folds of sufficient size to induce the formation of oil from the source rock. As these counties lie below the 55 isocarb, they should produce but little gas. The

Corniferous and Clinton offer possibilities in Lewis County; but the Berea is probably the only sand offering possibilities in Greenup and Boyd counties, because of the depth of the Corniferous and Clinton. Owing to the uncertain nature of the Berea, the potential value of Boyd and Greenup counties is somewhat doubtful.

COUNTIES FAVORABLY LOCATED FOR GAS BUT NOT FOR OIL

All territory between isocarbs 60 and 65 may be considered potential gas territory, provided the sands are not so deep as to have the effect of raising the content above 65. This territory includes Elliott, Morgan, Menifee, Magoffin, Floyd, Knott, Breathitt, Owsley, Clay, Whitley, Laurel, Knox, Leslie, Perry, Letcher, and Pike counties. Any considerable uplift should produce gas in these counties in sands which are reasonably shallow. Little oil can be expected in this area, except Pottsville oil or extensions of the Wier pool of Lawrence-Johnson-Magoffin counties. As already stated, the Pottsville oil area cannot be profitably prospected.

COUNTIES FROM WHICH NO COMMERCIAL PRODUCTION CAN BE EXPECTED

It is useless to prospect for oil or gas in the counties lying above isocarb 65, which include Bell, Harlan, and the southern parts of Whitley, Leslie, and Pike counties. Prospecting in deep horizons is useless as isocarb 65 is approached. As Madison, Clark, Montgomery, Bath, and Fleming counties lie for the most part west of the outcrop of all the producing sands, they need not be considered. Powell, Rowan, and Carter counties do not contain folds of sufficient size to influence the formation or accumulation of oil.

It is evident from the foregoing study of possibilities of eastern Kentucky that the discovery of other large oil pools is very improbable. The areas favorable to oil production are very limited, and the lenticular character of the sands and close relation to major folding reduce this territory to an extremely small acreage.

The prospect for new gas fields is somewhat brighter, but a limited market will hamper extensive gas development for a long time to come.

URANIA OIL FIELD, LASALLE, WINN, AND GRANT PARISHES, LOUISIANA[1]

G. W. SCHNEIDER[2]
Shreveport, Louisiana

ABSTRACT

The discovery of oil at Urania is of two-fold importance, (1) because of the structural relationship with the Angelina-Caldwell monoclinal flexure and (2) because it is the first production of oil from beds of Tertiary age in northern Louisiana. This discovery led to an extensive drilling program along the Angelina-Caldwell flexure during the year 1926 when 225 wildcat wells were drilled. No new oil production was found but the Richland gas field was opened as the indirect result of this drilling program.

INTRODUCTION

The Urania field is situated in the east-central part of Louisiana, in T. 9 and 10 N., R. 1 and 2 E. The main part of the field is in LaSalle Parish, but it extends into Grant and Winn parishes. It is 100 miles southeast of Shreveport and 90 miles south of Monroe. The producing area is 3 miles wide and 10 miles long. It is divided into two areas which derive their local names from the towns located within the area, namely, the Tullos-Urania district on the north and the Georgetown district on the south.

Comparatively little has been published on the Urania field and the Angelina-Caldwell flexure region.[3] Most of the information upon which this paper is based has been obtained from well logs, the accuracy depending upon the care in drilling. Most of the major companies had geologists at the wells until the key horizons were cored; otherwise the correlation was made by comparison of well logs. The companies in this district have been generous in supplying information on the wells, which the writer gratefully acknowledges.

TOPOGRAPHY

The Urania field lies in a gently rolling plain, on which the altitudes range from 60 feet above sea-level along the principal streams to 130 feet

[1] Presented by title before the Association at the Tulsa meeting, March 26, 1927. Manuscript received by the editor, October 8, 1927. Published by permission of The Texas Company.

[2] Geologist for The Texas Company.

[3] L. P. Teas, "Urania," in *Petroleum Development and Technology in 1926*, A.I.M.E., p. 683, 1927.

above sea-level along the divides. Adjoining this area on the south is the Kisatchie Wold, consisting of rocky hills extending across the state of Louisiana westward into Texas and eastward into Mississippi. This ridge consists of hard sandstones and quartzitic layers with alternating clays; owing to differential erosion this province is a marked contrast to the region immediately north.

The main drainage of the area is through Castor Bayou, which flows in a general southerly direction; the Urania field is drained by several smaller streams tributary to Castor Bayou.

HISTORY

The first wells in the Urania field were drilled in the latter part of 1924 and early part of 1925. Five wells were drilled by the Urania Petroleum Company in Secs. 18 and 20, T. 10 N., R. 2 E., LaSalle Parish, all of which yielded showings of oil and gas. Because of the showings encountered in these wells the Urania Petroleum Company's Urania Lumber Company No. 6 well was located by H. G. Schneider and W. R. Julian in Sec. 18, T. 10 N., R. 2 E. This well came in March 25, 1925, flowing at the rate of 800 barrels per day. It produced at this rate for several hours and then sanded up. Cleaning and repairing were unsuccessful and it was abandoned as a failure. The first commercial well in the field was the Urania Lumber Company's No. 7, drilled by the Urania Petroleum Company in Sec. 19, T. 10 N., R. 2 E., which was completed August 4, 1925, yielding 10 barrels of oil per day. Activity lagged for a few months, but in September, 1925, Beckman and Freeman's No. 2, in Sec. 25, T. 10 N., R. 1 E, blew out and cratered at depth of 1,000 feet. The showing of this well stimulated activity, and drilling has continued to the present time. The peak of production was in October, 1926, when the average daily production was 16,585 barrels, exceeding the production of any other of the Louisiana fields. At the present time, 22 months after its discovery, it is producing 10,084 barrels daily. The total production to September 1, 1927, is 6,588,819 barrels.

GEOLOGY

STRATIGRAPHY

The rocks at the surface in the region of the Urania field belong to the Jackson and the Yegua formations of the Eocene group of the Tertiary. The greater portion of the field is covered with stream deposits; outcrops of the underlying stratified rocks are scarce. A generalized geologic column for the Urania field is here given.

GENERALIZED SECTION OF FORMATIONS IN THE URANIA FIELD

	Feet
Tertiary	
Eocene	
Jackson formation	200
Claiborne group	
Yegua formation	500
St. Maurice (restricted)	185
Sparta sand	430
Cane River	220
Wilcox	1500±

SURFACE GEOLOGY

Jackson formation.—The Jackson formation is at the surface in the greater portion of the Urania field. The contact of the Yegua and the Jackson formations can be seen on the south and east sides of the field. The Jackson formation is marine; it is made up chiefly of light gray fossiliferous clay with glauconitic sands at the base. It has a maximum thickness of 200 feet in the producing area (Fig. 1), but in the Dixie Oil Company's L. & A. No. 1, in Sec. 29, T. 9 N., R. 2 E., 8 miles south of the Urania field, its thickness is 530 feet.

Claiborne group.—The Claiborne group is divided into the Upper Claiborne, represented by the Yegua formation, and the Lower Claiborne,[1] represented by the St. Maurice (restricted), Sparta sand, and Cane River.

Yegua formation.—The Yegua formation is made up of light gray and brown laminated sandy clays and massive gray sands. Weathered exposures are generally red and brown, owing to the oxidation of the beds. The Yegua formation is non-marine, containing no fossils except fossil leaves in the laminated gray clay members of the formation. The formation has a thickness of 500 feet.

UNDERGROUND GEOLOGY

St. Maurice formation (restricted).—This formation and those described hereafter do not crop out in the field. The St. Maurice formation is made up of alternating beds of sandy clay, massive beds of glauconitic sand, laminated beds of sands, lignitic clays, and indurated beds of sandstone, containing many fossil casts. The prevailing colors are light gray and brown. The formation is about 185 feet thick in the field.

[1] W. C. Spooner, "Interior Salt Domes of Louisiana," *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 3, 1926.

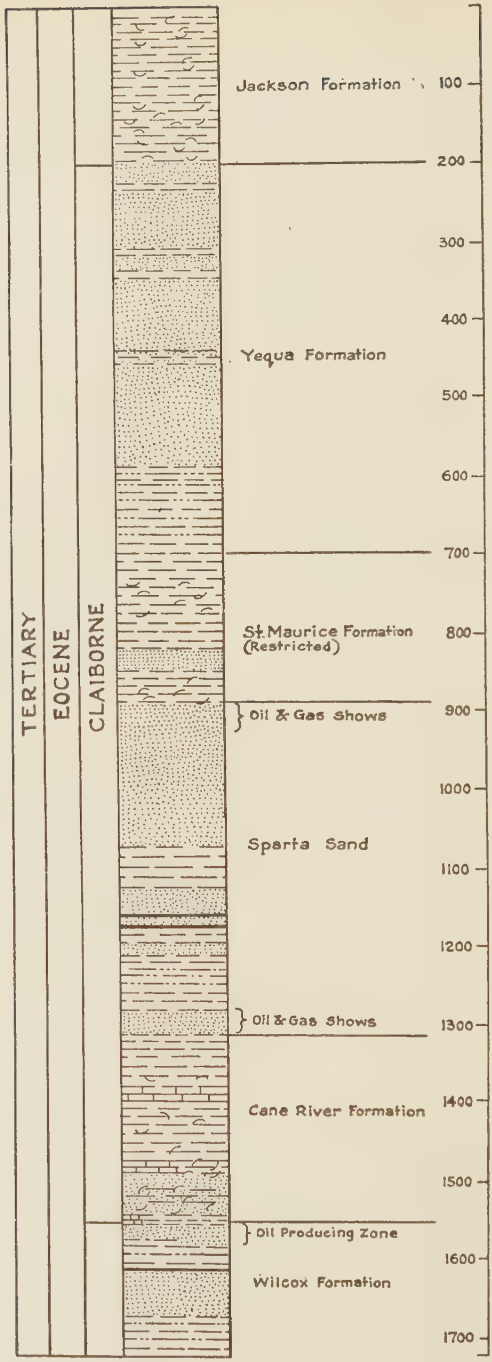


FIG. 1.—Stratigraphic section of Urania district. Depths shown in feet.

Sparta sand.—The Sparta sand is dominantly sandy but contains some beds of clays and sandy clays. The basal 30 feet of the Sparta sand is a massive sand, which has yielded showings of oil and gas. It is followed by 100 feet of interbedded clay and sand. Overlying this member is 40 feet of sand, in part lignitic, which is followed by 80 feet of dark gray to brown micaceous and lignitic clay, containing fossil leaves. The upper 180 feet is made up of massive sands. In general the sands are gray and the clays light gray to brown with the brown predominating. The Sparta sand has a thickness of 430 feet in the Urania field.

Cane River formation.—The upper part of the Cane River formation consists of brownish fossiliferous clay and sandy clay which grades downward into greenish-gray, highly fossiliferous marl with irregularly distributed glauconite. The basal part of the formation is glauconitic sand, which on the east side of the field contains disseminated pyrite. The top and bottom of the Cane River formation are the best key horizons in the area; the fossiliferous brown clay at the top is easily distinguishable from the Sparta sand above, and the partly indurated glauconitic marl, called "salt-and-pepper sand" by the drillers, contrasts sharply with the underlying sand and sandy clay of the Wilcox formation. The Cane River formation is uniform in thickness and character throughout the field, where it has an average thickness of 220 feet.

Wilcox formation.—The Wilcox formation is made up of lenticular beds of sands and clays, in part lignitic, with a predominance of white micaceous sandy clays. The lignite is especially plentiful in the upper part of the formation. Clay-balls and siderite concretions are common in the clay members of the formation. Several wells drilled in the field found thin beds of glauconitic sands in the upper part of the Wilcox formation. The Simms Oil Company's Urania Lumber Company No. 1, in Sec. 8, T. 10 N., R. 2 E., penetrated 1,950 feet of the formation and probably was not through the formation at 3,518 feet, which was the total depth of the well. The thickness of the Wilcox formation is not known in the Urania field, but probably is not less than 2,000 feet. Production is found in the top of the Wilcox formation ranging from 1,480 to 1,600 feet in depth.

Oil and gas horizons.—The oil production in the Urania field is obtained from the topmost beds of the Wilcox formation. Showings of oil and gas have been encountered in the upper and lower beds of the Sparta sand, in the basal bed of the Cane River formation, and in a few wells drilled on the highest parts of the structure, in the top of the Yegua formation. Some of the deeper wells have had showings of oil and gas about 570 feet below the top of the Wilcox formation.

STRUCTURE

SURFACE

Because of the low dips, the scarcity of outcrops, and the alluvium which covers a large part of the surface, the structure of the Urania field is not easily determined from the surface exposures. The contacts between the Yegua and the Jackson and between the Jackson and the Catahoula formations bend south around the field indicating some form of structural relief. This feature is best shown by the Jackson and Catahoula contact, as shown in Figure 2. The contact trends northeast from the northwest corner of Grant Parish to the northern part of T. 9 N., R. 2 E., LaSalle Parish, where it bends around T. 10 N., R. 3 W., and continues N. 45° E.

SUBSURFACE

In the north-central part of Louisiana the general southward slope of the Coastal Plain sediments is interrupted by a large regional monoclinal flexure, which extends from Texas across Louisiana and into Mississippi. This monoclinal flexure trends N. 65° E. across Sabine, Natchitoches, and Winn parishes. Near the town of Urania the trend changes to N. 45° E. and continues in that direction through Caldwell Parish. This monoclinal flexure, known as the Angelina-Caldwell flexure,[1] is defined as that area wherein there is a marked increase in the dip of the strata. The beds north of the flexure have a gentle gulfward dip which on the flexure increases to as much as 180 feet per mile. This feature is well illustrated in Sabine Parish, where the beds dip 180 feet per mile, which is greater than in any other part of the Angelina-Caldwell flexure.

The structure of the Urania field is in the form of a flat terrace, 20 miles long and 8 miles wide, with the long axis trending northeast and southwest. On the terrace is an elongate asymmetrical anticline with a closure of 50 feet. The highest part of the anticline is at the town of Tullos. The change in strike of the beds at Urania has resulted in the formation of three distinct structural noses which radiate southeastward from the terrace.

The Tullos-Urania terrace, which extends in a northeasterly direction from Georgetown to Urania and east of Castor Bayou, has produced the greater portion of the oil from the Urania district (Fig. 3). This structure has low relief, consisting of three separate closures, all of which are productive. The highest part of the most northerly closure is south of Urania in the south half of Sec. 18, T. 10 N., R. 2 E., and the most southerly closure is in Sec. 2, T. 9 N., R. 1 E. The Tullos-Urania area is

[1] A. C. Veatch, "Geology and Underground Water Resources of Northern Louisiana and Southern Arkansas," *U.S. Geol. Survey Prof. Paper 46*, 1906.

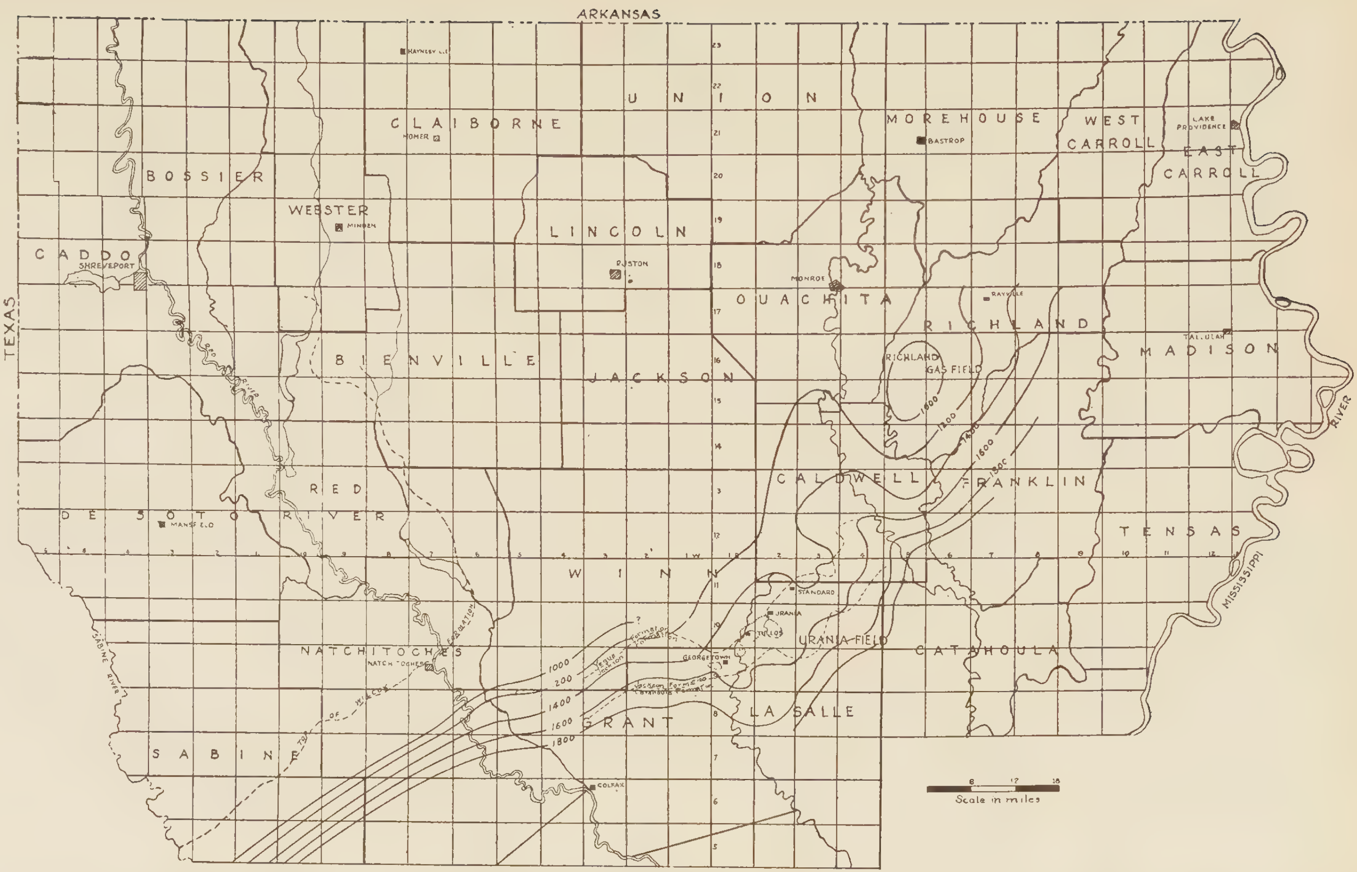


FIG. 2.—Geologic structure map, showing Angelina-Caldwell flexure. Contours drawn on the top of the Wilcox formation below sea-level. Interval, 200 feet.

separated from the area on the north by a syncline, and from the area on the south by a low saddle. Throughout the field the dip is uniform at

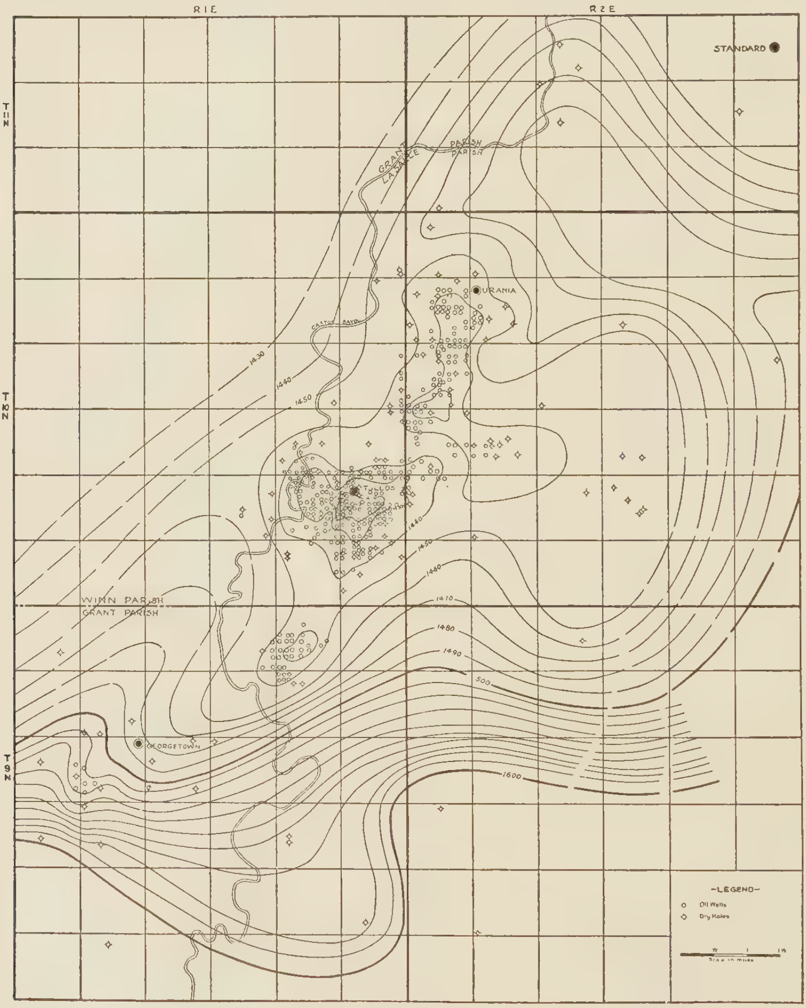


Fig. 3.—Geologic structure map of Urania field, showing contours on the top of the producing sand below sea-level. Interval, 10 feet.

30 feet per mile, but south of the producing area it increases to 50 feet per mile. On the northwest side of the field the dip is approximated because of the lack of sufficient data.

The small production that is found south of Georgetown, in Secs. 17 and 18, T. 9 N., R. 1 E., is located on a southeastward-plunging nose. In the southern part of the township the dip is about 40 feet to the mile and increases toward the synclinal areas on the west and the northeast to about 55 feet per mile. In this area production is found from 1,500 to 1,540 feet below sea-level, approximately 75 feet lower than the water level of the Tullos-Urania area.

RELATIONSHIP OF OIL AND GAS TO STRUCTURE

The oil in the Urania field is accumulated in a sand in the upper part of the Wilcox formation along the disconformable contact with the Cane River formation. The top of the Wilcox formation is an irregular erosion

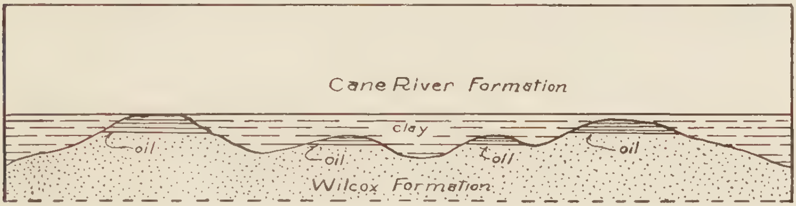


FIG. 4.—Sketch showing the attitude of the producing sand at the disconformity between the Cane River and the Wilcox formations.

surface upon which the Cane River beds were deposited, a condition which is shown by the irregularity of the producing sand (Fig. 4).

In most places the producing sand is overlain by brown lignitic clay with a maxium thickness of 40 feet, or by a thin bed of lignite; but in the Georgetown area, in T. 9 N., R. 1 E., the green-sand marl of the Cane River formation lies directly above it. In Secs. 23 and 25, T. 10 N., R. 1 E., the producing sand has not been found in several wells, and a larger interval of clay and lignite occurs below the Cane River formation. There is a lack of regularity in the beds at the contact of the Wilcox and the Cane River formations. In some places, particularly in the Tullos area, in Sec. 26, T. 10 N., R. 1 E., the highest part of the structure, and in some of the wells drilled on the east side of the field, a bed of lignite 3–5 feet thick is found above the oil sand. This lignite bed above the oil sand is absent in wells south of Tullos at Georgetown and in general on the west side of the field. In the Tullos-Urania district the oil sand is found below lignitic clays and indurated marls. In several wells recently drilled showings of oil have been encountered in a glauconitic sand which lies below sandy lignitic clay and above the producing sand. This horizon is 10–20 feet above the producing sand.

The producing sand is composed of fine-grained white subrounded quartz grains, generally unconsolidated, so that wells ordinarily drill themselves deeper after completion. Salt water is found at an average depth of 1,450 feet below sea-level, which is considered the water-level of the field. The production found south of Georgetown, in Secs. 17 and 18, T. 9 N., R. 1 E., is 75 feet lower than the water-level of the Tullos-Urania district.

PHYSICAL AND CHEMICAL CHARACTER OF THE OIL

The oil of the Urania field averages about 21.5° Bé. and is of a brownish-black color similar to the Gulf Coast crude oils. The following tables give an analysis of the oil.

ANALYSIS OF URANIA CRUDE OIL*

Specific gravity	.923	Baumé gravity	21.9°
Per cent sulphur	0.30	Per cent water	6.9
Odor	Peaty	Color	Brownish
Fire test	330° F.	Viscosity at 100	650° F.
Pour test	0° F.	Flash	265° F.

VACUUM CRUDE RUN

Cuts	Per Cent Cut	Vapor Temperature	Viscosity
1	2.4	260° F.	42
2	2.4	380	43
3	2.0	410	45
4	3.1	422	49
5	4.8	432	62
6	3.3	445	83
7	6.0	458	51
8	4.1	468	123
9	4.5	480	214
10	3.0	492	407
11	5.0	504	124
12	4.9	518	53
13	6.2	531	733
14	3.1	542	1,144
15	6.0	588	2,207
16	5.2	600	721
17	5.2	Fire cut	4,803
18	5.2	....	277
19	2.0	....	1,389

SUMMARY OF CRUDE RUN

	Percentage	Gravity	Flash	Fire	Viscosity	Pour
Gas-oil	20.8	29.3	205° F.	240° F.	52	0° F.
Untreated lubricating distillate	58.4	22.5	325° F.	380° F.	354	0° F.
Residue	13.2	Soft flux oil		......	......	......
Water	6.9	......	......	......	......	......
Loss	0.7	......	......	......	......	......

Ratio oil distilled to steam used, 2.36 to 1.

SUMMARY OF LUBRICATING DISTILLATE RE-RUN

	Percentage	Gravity	Flash	Fire	Viscosity	Pour	Color	Sulphur (Percentage)	Carbon Residue (Percentage)
Gas-oil	1.2	29.3	200	235	60	0	......	......	......
Light lub. oil	36.0	26.7	300	345	101	1	dark	.18	.019
Med. lub. oil	19.0	24.0	355	395	293	0	dark	.22	.112
Heavy lub. oil	29.1	22.9	455	515	967	0	dark	.26	.566
Cyl. oil	10.6	20.1	510	585	135–210	20° F.	dark	.26	1.46
Residue	2.3	......	......	......	......	......	......	......	......
Loss	1.8	......	......	......	......	......	......	......	......

Ratio oil distilled to steam used, 1.0 to 1.06.

GRAND SUMMARY

	Percentage
Gas-oil	21.4
Light lubricating oil	18.9
Medium lubricating oil	10.0
Heavy lubricating oil	15.3
Cylinder oil	5.6
Residue	14.4
Water	6.9
Loss (total)	7.5

* Analysis of Urania crude furnished by refining department of Louisiana Oil Refining Corporation, Shreveport, Louisiana. Date, April 11, 1925.

There is little gas with the oil in the field. Flowing wells are of short duration. Several attempts have been made in the field to produce gas for fuel purposes from the Wilcox sand and the higher formations without results.

WATER

Most of the sands encountered in drilling carry plenty of water, which, together with the bottom water, presents a difficult problem to the opera-

tor. All of the wells completed in the field have an initial water content ranging from 10 to 30 per cent of the total fluid, all bottom water. The water increases rapidly to 75 per cent, from which point the increase is slow, finally settling to about 85 per cent water and 15 per cent oil.

The 1,450-foot contour marks the salt-water level, and very few producing wells have been completed below this depth. In the Georgetown area the salt-water content is greater than in any other part of the field. Wells here have an initial production of 10 per cent oil and 90 per cent salt water, with the water content increasing so rapidly that the wells are abandoned as unprofitable soon after completion. The Georgetown area has produced to date about 75,000 barrels, which is a very small part of the total yield of the Urania field.

OIL AND GAS PRODUCTION

Rotary drilling is used entirely in the field. A well is commenced with a 15-inch bit and the hole is drilled to a depth of 100 to 150 feet, where 10-inch casing is set to exclude the surface water. Drilling is continued until the basal green-sand of the Cane River formation, called by the drillers "salt-and-pepper sand," is reached, at depths ranging from 1,450 to 1,600 feet, depending upon the location of the well with reference to the structure. Most operators use 6-inch casing, which in the Georgetown area is set as near as possible to the top of the producing sand, although in the Tullos-Urania area it is set in the clay about 30 feet above the sand. The casing is set with 75 to 100 sacks of cement and allowed to stand for at least six days. The single-plug method for setting casing is the most widely used. At the end of six days the plug is drilled, the casing tested, and the well is ready to drill in. Most wells are finished with a screen-liner. Perforated pipe has not been found practical in this area because of the fineness of the sand. Many different sizes of screens are used, depending upon the operator. A 30-inch mesh is most commonly used. In the Urania field wells are completed producing as much as 1,500 barrels a day; decline is ordinarily rapid. As the average well in the field makes a high percentage of salt water, several mechanical methods are used for raising the fluid. Practically all the wells are placed on the beam in a comparatively short time. Standard-rig pumps, compressed air, and swabbing are used. Compressed air is used in many wells, especially where large quantities of fluid must be handled to secure a maximum amount of oil. The central-pipe system is used, the air being forced down 2-inch tubing inside of the 6-inch casing and wells making as high as 2,200 barrels of fluid, containing 96 per cent salt water, are operated at a profit. The

average well is completed in 4–12 days. The highest point in production in the field was reached in October, 1926, with a production of 514,135 barrels. Since then the decline of the field has been steady, with a production in August, 1927, of 312,604 barrels. Table I gives the entire production of the field up to the present.

TABLE 1

	Average Daily Production (Barrels)	Number of Wells	Average Production per Well (Barrels)	Total Production for Month (Barrels)
November, 1925, to February, 1926	.....	.....	.....	11,550
February	1,939	31	63	54,292
March	6,239	68	92	193,409
April	9,843	154	64	295,290
May	12,960	187	69	401,760
June	14,567	206	71	437,010
July	13,168	200	66	408,208
August	13,583	253	54	421,073
September	14,894	277	54	446,820
October	16,585	358	46	514,135
November	13,582	328	41	407,460
December	13,061	322	41	404,891
1927				
January	12,927	339	38	400,737
February	13,123	347	38	367,444
March	11,514	347	33	356,934
April	10,386	346	30	311,580
May	8,537	365	23	264,647
June	9,343	350	27	280,290
July	9,635	286	33	298,685
August	10,084	295	34	312,604

To September 1, 1927, the field has produced 1,650 barrels of oil per acre from approximately 3,900 oil-yielding acres (Fig. 5). The ultimate yield per acre is estimated to be about 4,500 barrels.

The producing wells in the Urania field have a large content of water and emulsion, and the oil from all the wells requires dehydration. In the past few months the pipe-line companies are accepting the oil from the wells after the water has been separated by mechanical means. This benefits the small operator, who was compelled, heretofore, to treat the oil. Where the oil is treated by the operator two methods are used: one by the use of Tret-O-Lite, and the other by electrical dehydration. As there are no pipe lines to the field, the oil is gathered and loaded into tank cars and shipped to several refineries.

There has been a steady decline in production since the peak was reached in October, 1926. It is improbable that new wells will compensate

for the decline of the present wells, since the productive area has been outlined. Most of the horizons above the Wilcox formation have been tested; the deeper sands of the Wilcox offer some possibilities. Plans have been made by several companies for the joint drilling of a deep well,

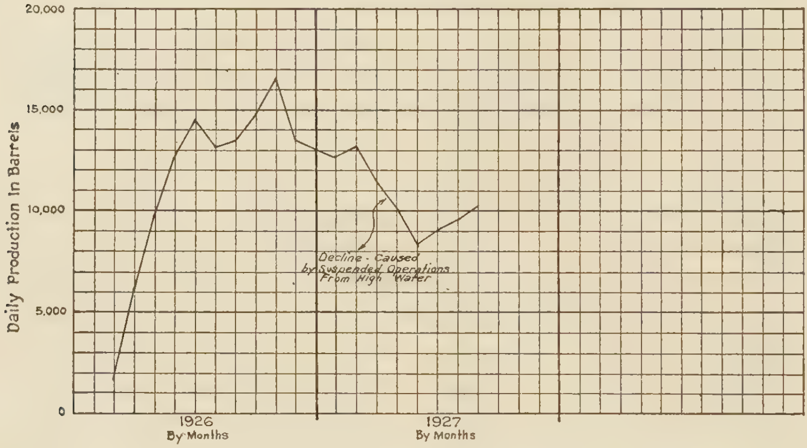


FIG. 5.—Production curve of Urania field.

which will probably be located in Sec. 25 or 26, T. 10 N., R. 1 E., on the most favorable part of the structure. Deeper production from the Cretaceous is considered unfavorable owing to lack of favorable reservoir sands within reach of the drill. In substance, the occurrence of oil in the Tertiary at Urania is due to the presence of a favorable sand at the disconformity between the Cane River and the Wilcox formations, together with minor folding.

GEOLOGY OF THE SAGINAW OIL FIELD, MICHIGAN, AND DISCUSSION OF MICHIGAN'S OIL PROSPECTS[1]

CHARLES GORDON CARLSON[2]
Tulsa, Oklahoma

ABSTRACT

The first drilling for oil at Saginaw was in 1912 by the Saginaw Valley Development Company. The wells were located on the south limb of the Saginaw anticline. Oil was found, though not in commercial quantities, in the "Saginaw sand"—a dolomitic lime in the Traverse formation. The discovery well leading to the present development was drilled in the fall of 1925 by the Saginaw Prospecting Company.

Most of the production is from the Berea sand, of Mississippian age, at depths ranging from 1,800 to 1,860 feet. Wells, after being shot, produce from 2 or 3 barrels to 40 barrels a day, depending upon location on structure and "tightness" of sand. The oil is of 46° Bé. gravity and contains about 48 per cent gasoline.

On June 1, two wells were producing from the Saginaw lime at a depth of 2,300 feet. This lime is in the Traverse formation, of Devonian age. Other wells drilled to this "pay," and favorably located, have been dry.

The total production of the field on June 1 was about 1,400 barrels a day from more than 190 wells.

The limit of the field is approximately defined, except at the southeast, where the trend of the pool is into the business district.

It is probable that additional production will be found in the eastern part of the state should conditions structurally favorable be found. The thickness of glacial drift and the absence of the Berea sand in western Michigan make this part of the state less favorable for oil and gas development.

SAGINAW OIL FIELD

LOCATION

The Saginaw oil field is in the east-central part of Michigan. The field is about three miles long and extends southeast from the NW. $\frac{1}{4}$ of Sec. 10, T. 12 N., R. 4 E., into the northwest part of the city of Saginaw.

STRUCTURE

The producing wells at Saginaw are located on the Saginaw anticline, a well-defined asymmetric fold trending northwest and southeast, and ex-

[1] Presented before the Association at the Tulsa meeting, March 26, 1927.

Manuscript received by the editor, June 13, 1927. Reprinted from *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 9 (September, 1927), pp. 959-65.

Published by permission of The Twin State Oil Company.

[2] Peerless Oil and Gas Company. The writer is indebted to Richard A. Smith, director of the Michigan Geological Survey, and to Wayland Osgood, the Survey's petroleum geologist, for kind co-operation in furnishing much of the information for this paper.

tending from the northeast half of Sec. 4, T. 12 N., R. 4 E., across the central part of the city of Saginaw. The data, though not conclusive, indicate that this anticline is located on a broad regional arch. The southeast limits of the structure and the amount of closure cannot be determined exactly owing to the absence of wells at this locality. The dip of the basinward or southwest limb of the fold is more than twice that of the northeast limb.

HISTORY OF DEVELOPMENT

Efforts to find oil at Saginaw were first made in 1912 by the Saginaw Valley Development Company. Ten wells were drilled in 1912 and 1913, two to the Traverse and eight to the Dundee.[1] The location of these tests was based on the best evidence of favorable structure available at that time. This evidence indicated the presence of an anticline trending southeast from a point about three miles west of Kawkawlin through Saginaw and Blackmar. The data were insufficient to indicate definitely the trend or position of the fold.

None of the wells drilled found oil in commercial quantities, though several of them obtained considerable oil from the Dundee (Corniferous) lime and a lime in the Traverse formation. The latter "pay," though a lime, was named the "Saginaw sand." The wells obtaining production were located in the city of Saginaw, near the Bristol Street bridge in the SW. ¼ of Section 24 (Fig. 1).

The discovery well, which led to the development of the Saginaw field, was drilled in the fall of 1925 by the Saginaw Prospecting Company, composed of Saginaw business men. This well, which produced about 20 barrels initially after being shot, is still producing several barrels a day. It is located about a mile and a half northwest of the wells which had some production in 1912 and 1913 and later development has shown it to be near the axis of the structure.

PRODUCTION AND SAND CONDITIONS

Most of the Saginaw oil is obtained from the Berea sand (Fig. 2) at depths ranging from about 1,800 to 1,860 feet, depending on the location of the anticline. The deepest producing well is the Sun Oil Company's Henry Deibel in the NW. ¼ of Section 10, the Berea here being found at 1,864 feet. This appears to be an edge well and approximately limits the northwest extension of the pool.

The Berea oil is found in the uppermost few feet of the sand. Below this "pay" there is a shale break and the sand below this shale carries water.

[1] Richard A. Smith, *Michigan Geol. Survey*, Publication 14 (11th ser.), p. 127.

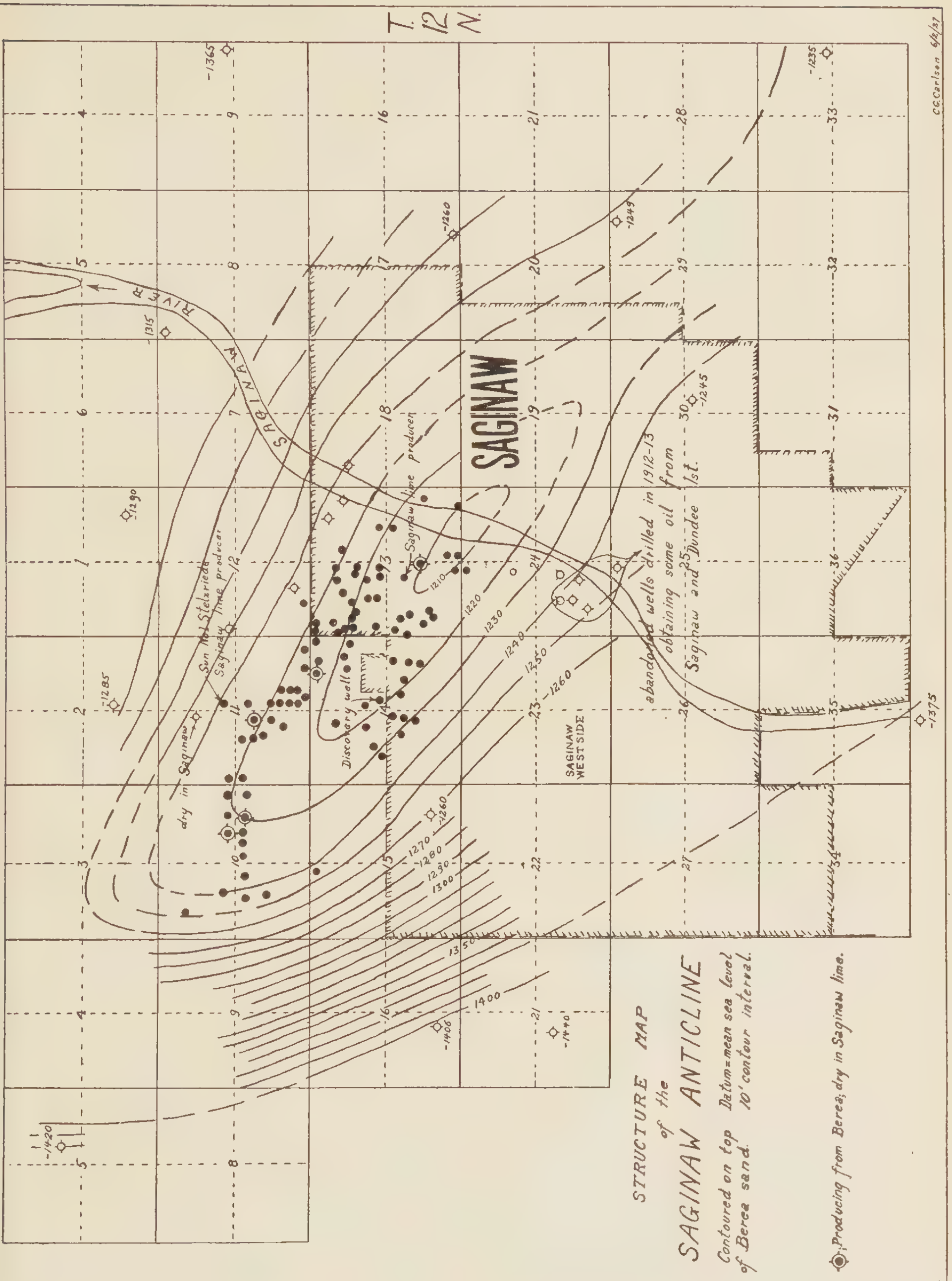

STRUCTURE MAP
of the
SAGINAW ANTICLINE
Contoured on top of Berea sand.
Datum=mean sea level
10' contour interval.
Producing from Berea; dry in Saginaw lime.
SAGINAW
SAGINAW WEST SIDE
SAGINAW RIVER
T. 12 N.
Discovery well
Saginaw lime producer
Sun No. 1 Stelzriede Saginaw lime producer
dry in Saginaw
abandoned wells drilled in 1912-13 obtaining some oil from Saginaw and Dundee 1st.
C.G. Carlson 6/2/37

FIG. 1

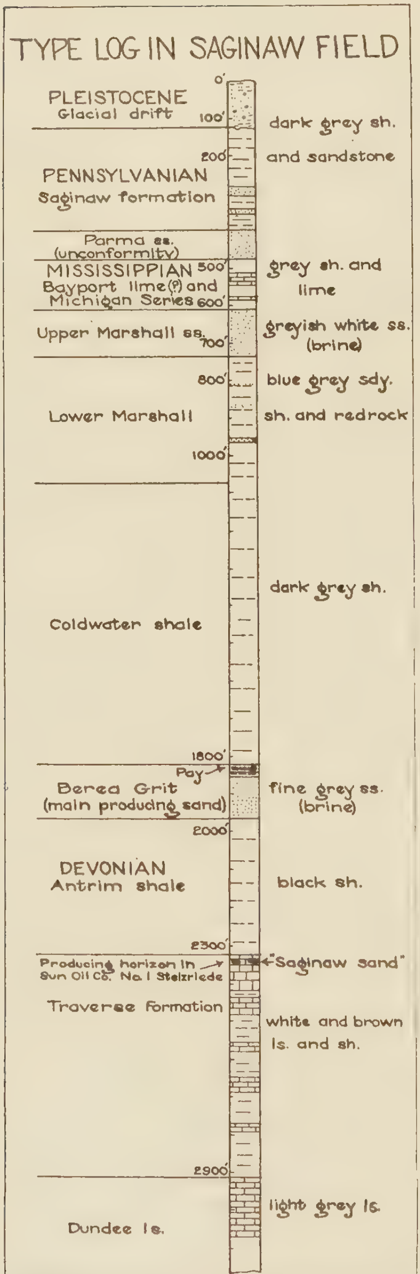


Fig. 2

Very little gas accompanies the oil. The wells are shot with 60 to 80 quarts of nitro-glycerin in order to be made commercially productive. The initial yield varies from 2 or 3 barrels to about 40 barrels a day. Wells drilled within the city limits in the southeast part of the pool have had the highest initial production. These wells are located near the top of the fold.

The decline in production is slow; some of the early wells in the field which yielded 15 to 20 barrels initially are still producing nearly this amount.

The Berea sand is fine-grained, most of the grains passing through 180-mesh. Locally the sand is cemented and very silty, so that there is considerable variation in yield from different wells in the same part of the pool.

There are at present two producing wells from the Saginaw lime—so-called "Saginaw sand"—of the Traverse formation, which is Devonian in age. This production comes from about 500 feet below the Berea. Several wells have tested the Saginaw lime and on favorable parts of the structure, surrounded by Berea production, but without success (Fig. 1). The Sun Company's Stelzriede No. 1, the Saginaw lime discovery well, which was drilled late in March, 1927, had an initial production of about

475 barrels. On June 1 this well was pumping 50 barrels daily. Production within the Saginaw lime seems to be determined as much by locally porous conditions within the lime as by location on structure. The producing part of the lime in the Sun Company's well is about 4 feet thick.

Below the Saginaw lime there is possibility of production from the Dundee (Corniferous) lime, the Monroe formation, and the Trenton limestone. These formations have been very productive in the Ontario fields and along the Cincinnati arch in northern Ohio.

Two wells have tested the Dundee lime in the Saginaw field: that of the Bliss Petroleum Company in the SW. $\frac{1}{4}$ of Section 10, and the J. and S. Development Company's well in the NE. corner of the SW. $\frac{1}{4}$ of Section 14. These wells both had encouraging showings, but owing to mechanical difficulties had not been completed as producers on June 1.

The depth to the Trenton limestone at Saginaw is probably about 5,500 feet.

On June 1, more than 190 wells in the Saginaw field were producing daily about 1,400 barrels. Less than 100 barrels of this production is from the Saginaw lime. Much of the production is from town-lot wells in the northwest part of Saginaw.

An analysis of Berea crude made by the Shaffer Refining Company at Cushing, Oklahoma, and obtained through the courtesy of James H. Gardner is given below.

CHARACTER OF THE OIL

Gravity 46.3° Bé.

	Per Cent		Per Cent
Gasoline	48	Wax oil	12
Kerosene	14	Residuum	6
Gas oil	20		100

OIL PROSPECTS ELSEWHERE IN MICHIGAN

On the areal geologic map (Fig. 3) are indicated localities at which oil has been reported from wells drilled for oil or gas. These showings in western Michigan were found in the top of the Dundee lime. The most encouraging showings were found at Allegan and Manistee. At Allegan the Dundee was found at depths ranging from 1,275 to 1,318 feet. Two of the wells for a time pumped 2 or 3 barrels daily. Very little gas accompanied the oil. At Manistee considerable oil and great gas pressure were found in a sandy limestone at 1,905 feet. As the Dundee cannot here be distinguished from the Monroe (Silurian) beds, the oil at Manistee may have come from the latter formation.

Oil was produced in small quantities near Port Huron from about 1898 to 1920 by the G. B. Stock Xylite and Grease Company. The oil was found in the sandy upper part of the Dundee limestone at depths ranging from 500 to 650 feet. The initial yield varied from 2 to 5 barrels a day,

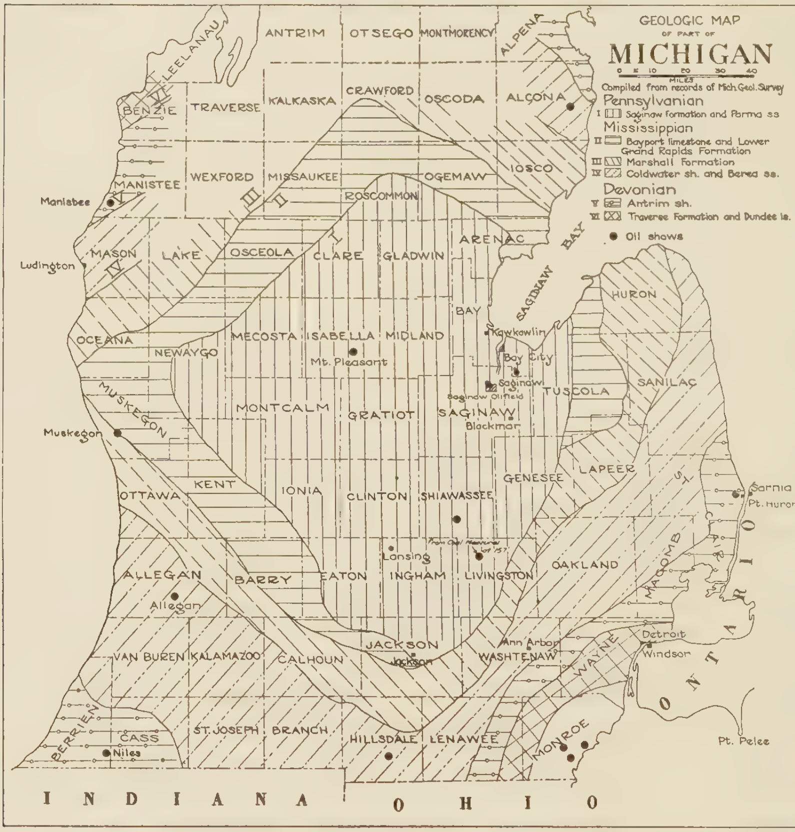


FIG. 3

which settled after a few months to a daily production of about half a barrel.

At Mount Pleasant a showing of oil of 47° Bé. gravity was found in a black sand at 2,590 feet, which is probably the Berea.

In Monroe County several of the wells drilled to the Trenton limestone have found some oil and gas, though not in commercial quantities. Monroe County is located well down on the northwest flank of the Cincinnati anticline.

The lower part of the Antrim shale is generally petroliferous and, according to Smith, "The Devonian formations, especially the Antrim and Dundee, can be traced across southeastern Michigan by a line of 'shale' and surface gas wells and gas springs."[1]

The southern peninsula of Michigan is structurally a broad, shallow basin, the deepest part of which is in Midland and Isabella counties. The development of the Saginaw field, on an anticlinal fold on the eastern side of this basin, suggests that other pools may be found in this part of the state, if structures favorable to oil accumulation are found.

The formations which may be productive of oil or gas are the Berea sandstone, the Traverse formation, the Dundee limestone, Monroe formation, and Trenton limestone. The Berea sandstone is present only in eastern Michigan, being absent in the western part of the state or represented there in places by red sandy shale.

As most of southern Michigan is covered by glacial deposits, structural data can be had only from well records. Owing to the lack of reliable records in many parts of the state, core drilling may prove practical where reliable markers can be had at shallow depths and where the glacial drift is not too thick.

The structure mapping which has been done on coal seams within the Saginaw formation indicates that such "structures" are depositional or due to slumping and settling of the coal beds and are not reflected in the lower strata. The top of the Marshall sandstone is the highest formation, stratigraphically, which can be depended upon for correlation purposes.

[1] *Op. cit.*, p. 128.

NOTE.—Since this paper was first published the production of the Saginaw field has declined rapidly. On December 1, 1928, there were 310 producing wells making a total of 460 barrels of oil a day.

The new field, two miles north of the city of Muskegon, was discovered, December 8, 1927, by the Muskegon Oil Corporation in the Traverse formation at a depth of 1,640 feet. The estimated initial production was 300 barrels. Several months later, one of the small producers, deepened to the Dundee dolomite at approximately 2,050 feet, found gas in commercial quantity. The initial production of the Dundee limstone wells was as high as 2,000 barrels a day but the decline has been rapid owing to incursion of bottom water and depletion of gas pressure by letting the wells flow without back pressure.

On December 1, 1928, there were approximately 100 producing wells in the Muskegon area, most of them in the original pool which is a dome centering in Sections 8 and 9, T. 10 N., R. 16 W. Several other pools had been discovered in the vicinity. The production of December 1 was 3,100 barrels a day, but most of the Dundee dolomite wells were pinched to a production of 100 barrels a day because they were making from 2 to 60 per cent water. The oil has a gravity of 38.5° Bé. It contains 33 per cent gasoline and .38 per cent sulphur. The oil from the Traverse limestone does not contain sulphur. The gas wells have an initial capacity of approximately 10,000,000.

ARTESIA FIELD, EDDY COUNTY, NEW MEXICO[1]

MORGAN J. DAVIS[2]
Roswell, New Mexico

ABSTRACT

The Artesia field is of considerable interest to geologists since it is the first and the only commercial oil field so far discovered in the eastern half of New Mexico. Most of the information regarding the geologic column has been gained from the study of samples and logs of drilling wells, as there are no outcrops in the vicinity of the field. The deepest wells were in limestone at the bottom. The section drilled shows 4,000 feet of Permian sediments, half of which is marine dolomite. It resembles the Permian section in southwest Texas. It is thought that the whole column is Double Mountain and Clear Fork in age. Conditions of deposition in the Artesia field are very similar to those that prevailed over the whole of the great Permian basin; few fossils are found. The structure is a northeast-trending anticline. Production is on the apex and southeast flank of this structure. The producing portion of the geologic section is a zone rather than a definite horizon. The source rocks are the Permian dolomites and associated shales. The Artesia field is an orthodox example of anticlinal collection. The question of porosity enters into the problem in a large measure. The porous producing spots appear to be located by chance. The oil has a mean gravity of 37° Bé. Gas is one of the marketable products of the field. The composite decline curve fixes the life of the field at four years from discovery. Shooting improves the wells, and absence of water troubles makes development much cheaper. There is a possibility that additional pools of the Artesia type will be discovered in this general area.

INTRODUCTION

The Artesia field is of considerable interest to geologists whose work is mainly in the Permian basin area because it is the first and the only commercial oil field so far discovered in the eastern half of New Mexico. This field, together with the small wells found at considerable depths in what is known as the "Maljamar pool" farther east in Lea County, has been largely responsible for keeping interest and leasing activities alive in southeastern New Mexico up to the time the Hendricks pool in Winkler County, Texas, was discovered.

The writer is indebted to Wallace E. Pratt and Eugene Holman, under whose direction work in this area was done, for permission to present this paper, to Sidney Powers for helpful encouragement in the preparation of the paper, and to H. E. Munson for the preparation of the production-decline curve and other production information.[3]

[1] Presented by title before the Association at the Tulsa meeting, March 26, 1927. Manuscript received by the editor, October 3, 1927.

[2] Geologist for Humble Oil and Refining Company.

[3] Since this paper was written the U.S. Geological Survey has issued a structure contour map of the field by C. E. Dobbin, Foster Morrell, *et al.*, dated May 1, 1928, with no accompanying text.

LOCATION AND EXTENT

The Artesia field lies 14 miles, by auto highway, southeast of the town of Artesia, Eddy County, New Mexico. The extreme limits of the field as outlined by present development are contained in a rectangle approximately 8 miles wide and $7\frac{1}{2}$ miles long. Excepting the "Empire pool," most of the production has been obtained in the west half of T. 18 S., R. 28 E. The alignment of the field is generally northeast-southwest. The "Empire pool" is northwest of the main part of the field, and, as so far developed, lies in Sec. 35, T. 17 S., R. 27 E., and Sec. 2, T. 18 S., R. 27 E.

TOPOGRAPHY AND DRAINAGE

The general topography of the area may be described briefly as a system of erosional terraces, with many irregularities, rising from Pecos River successively toward the east until the escarpment of the west edge of the Llano Estacado is reached in Lea County. The Artesia field is situated on the first major terrace east of Pecos River.

The surface in the immediate area covered by the Artesia field is gently rolling. It furnishes a relief of approximately 100 feet from the south end, where an altitude of 3,550 feet is recorded to the north end of the field with an altitude of 3,660 feet.

There are no well-developed drainage channels. Shallow dry arroyos drain eastward away from Pecos River. These arroyos disappear in the sands toward the east. The water they carry disappears underground through sink holes.

HISTORY

V. H. McNutt, of Tulsa, Oklahoma, is the geologist who is credited with making the location that brought in the Artesia field. Several wells had been drilled west of the Pecos with encouraging showings of oil, and many of the artesian wells drilled in the Pecos Valley had found both oil and gas showings. The flow of artesian water had caused much trouble. Mr. McNutt suggested that a well be drilled on the east side of Pecos River on a block held by Flynn, Welch, and Yates, a partnership. This well was located in Sec. 31, T. 18 S., R. 28 E. It was completed at a depth of 1,930 feet in August, 1923. A million and a half feet of gas and some oil were obtained. This well was shut in for a fuel supply. Well No. 2 was drilled in Sec. 25, T. 18 S., R. 27 E., and in February, 1924, came in with 2,500,000 feet of gas at a depth of 2,085 feet. The partners then decided to move down dip toward the east, and well No. 3 in Sec. 32, T. 18 S., R. 28 E., was completed on April 9, 1924, as a 15-barrel well at a depth of 1,947 feet. This well attracted much attention and many operators began

to acquire acreage in the vicinity. As the next important development a group of mining men known as the Picher Oil Company, from Joplin, Missouri, and Picher, Oklahoma, moved up into Sec. 12, T. 18 S., R. 27 E. In August, 1924, this well made a natural flow from 1,957 feet, was shot, and settled to 10 barrels. The next important well was the Twin-Lakes No. 2 in Sec. 28, T. 18 S., R. 28 E., which was completed late in 1924 at a depth of 2,070 feet. This well made several natural flows, and when shot had an initial production of more than 250 barrels a day. Since that time drilling progressed rapidly and the Artesia field became a reality.

Virtually all of the producing wells of the Artesia field are situated on State of New Mexico leases.

GEOLOGY

STRATIGRAPHY

Information regarding the geologic column has been gained mainly from a study of well logs and samples furnished by the drilling program. There are no outcrops in the vicinity of the field. The surface is covered with loose sandy deposits, and locally, Quaternary caliche. Between the field and Pecos River is a zone in which the Permian Red-beds crop out. This series has thin dolomitic limestones and beds of gypsum intercalated in it. Appreciable surface slumping is manifest on every hand in this area, due to the leaching of the highly soluble underlying beds.

The deepest wells in the Artesia field, namely, the Ohio Oil Company-New State Oil Company's State No. 9, total depth 4,035 feet, and the Texas Production Company-Levers' State No. 5, total depth 3,633 feet, in Secs. 4 and 5, respectively, of T. 18 S., R. 28 E., were in dolomite and limestone at the bottom of the hole.

This dolomite section was approximately 2,000 feet thick from the top to the point at which the drill stopped. Beds and massive sections of black, gray, brown, and white dolomites, with a few sandy phases in all, were recorded throughout the column. A few beds of gray or white sand ranging from 5 to 20 feet in thickness break the dolomite series. The upper 300 feet of the dolomite appears to be more sandy than the lower series and contains at its base the principal pay horizon of the north part of the field. This is known locally as the "New State pay." In the central and southern parts of the field the principal oil-bearing horizon is in the top 100 feet of the sandy dolomite section. This is known as the "Maljamar pay."

Above the top of the dolomite measures is an anhydrite series broken here and there by beds of red sandstone or red shales. This series is ap-

proximately 1,100 feet thick. About 400 feet above the top of the dolomite, in the anhydrite section, is a prominent bed of hard red sandstone that occurs generally throughout the field. This bed ranges in thickness from 20 to 50 feet, and has been used extensively as a key bed for sub-

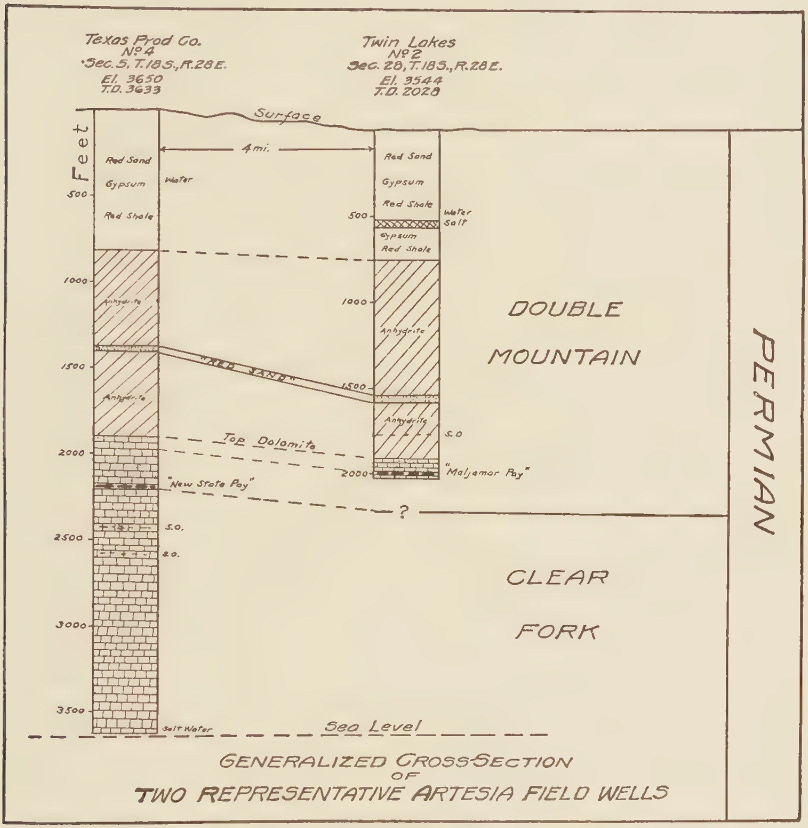


FIG. 1

surface mapping. In some wells this stratum carries showings of both oil and gas.

Above the anhydrite column and continuing to the surface are 700 feet to 900 feet of red shales, red sands, thin beds of gypsum, and stringers of dolomitic limestone. In the east half of T. 18 S., R. 28 E., wells encounter a short section of salt ranging from 25 to 150 feet in thickness. The western margin of the upper Permian salt basin bisects T. 18 S., R. 28 E., in an approximately north-south line.

It is unlikely that any of the material penetrated in the Artesia field proper is of Triassic origin, although wells only a short distance east of the field penetrate several hundred feet of the lower Dockum series. The whole section penetrated in the Artesia field is almost certainly Permian in age.

Although it is outside the scope of this paper to enter into the perplexing problems of stratigraphic correlation that have perturbed West Texas and New Mexico geologists, a few observations regarding correlation are offered here.

In general the Artesia field section resembles and suggests the southwest Texas sections encountered in Reagan, Crane, Upton, and Andrews counties. The dolomite section, particularly, very closely resembles, lithologically, the dolomite section found in those counties. None of the wells drilled in the Artesia area has furnished paleontological evidence for correlation, as the limestones encountered are barren of recognizable fossils. Field work by the writer has indicated that the top of the dolomite in the Artesia field comes into the section in the lower half of the Capitan dolomite in the Guadalupe Mountains. If this correlation is correct, then the age of the top of the dolomite in the Artesia field is assumed to be Double Mountain according to correlations used by many geologists in West Texas and New Mexico at the present time. Likewise the age of the anhydrite–red shale series above the dolomite is rather definitely shown in the field to be upper Capitan in age. This would relegate this series also to the Double Mountain period of deposition.

If thicknesses remain constant within limits of several hundred feet, then a correlation of the lower portion of the dolomite section with the Clear Fork epoch does not seem unreasonable.

The Permian beds previously mentioned as cropping out west of the Artesia field belong in the upper, or Red-bed, series. About 300 feet of section has been measured on these outcrops.

DEPOSITION

The conditions of deposition at the time the Artesia section was laid down are thought to be much the same as those that prevailed throughout the greater portion of the great Permian basin that comprises the whole of southeastern New Mexico and West Texas. The major vertical changes in the section in this area are thought to have occurred at approximately the same time.

The dolomite of the Artesia field was laid down under epicontinental marine conditions, but the sea waters during the major part of the period

were saturated with various salts to the point where the development of a normal fauna, that might be expected to occur in a late Carboniferous sea, was discouraged. In only one well of the Artesia field is it known authentically by the writer that fossils were found. This was in the Texas Production Company's deep well in Sec. 5, T. 18 S., R. 28 E. At a depth of 3,567 feet, fragments thought to be broken *Bryozoa*, *Crinoidea*, and *Spongiae* were found. None of the forms were in a condition to permit identification. The lack of the common marine fossils, together with the dolomitic character of the limestones laid down, would indicate some restriction of the seas. At the close of this period a very marked increase in the restrictive conditions precluded further limestone deposition and started the precipitation of anhydrite. Further desiccation was responsible for the salt measures.

SURFACE STRUCTURE

The beds already described as exposed west of the Artesia field have been used as key beds in the mapping of surface structure in T. 18 S., R. 27 E. Although an immense amount of slumping is present, when sufficient care was used in choosing stations it was found, in general, that surface structural highs corresponded with the subsurface. The discovery well of the Empire Gas and Fuel Company's "pool," drilled in Sec. 35, T. 17 S., R. 27 E., was located on a small surface dome. This surface structure has been found to check satisfactorily with subsequent information disclosed by drilling. The key beds used in this surface work were thin dolomitic limestones interbedded with red shales and gypsum.

SUBSURFACE STRUCTURE

Regional folding in northern Eddy County and southern Chaves County appears to take rather uniformly a northeast-southwest trend. A large overthrust fault, 35 miles west of Artesia, can be traced for nearly 40 miles on the surface along a trend of N. 45° E.

The alignment of the fold responsible for the Artesia field accumulation is no exception to the regional trend.

The subsurface structure of the Artesia area, based on a prominent marker 400 feet above the top of the dolomite, is shown on the accompanying contour map (Fig. 2). It may be described as a large northeast-trending anticlinal fold with subsidiary nosing or terracing on which the main part of the Artesia field in T. 18 S., R. 28 E., is located. The "Empire pool," Sec. 35, T. 17 S., R. 27 E., appears to be located at or near the apex of the main fold.

A series of subsurface maps of the field contoured on different horizons has shown that folding becomes more acute with depth and that warping has continued throughout the deposition of the entire section. This has necessarily resulted in a slight convergence of beds on the structural highs and divergence of beds in the synclines. The salt margin that extends

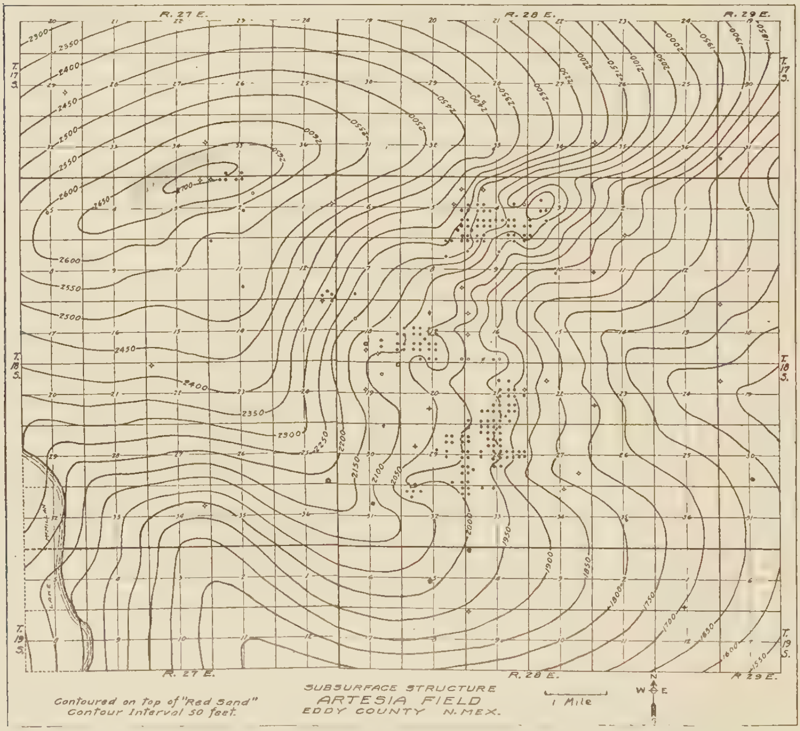


FIG. 2.—Contours on the top of the "Red sand," above sea-level.

through the field reflects this continuous folding, the margin running up into the re-entrants at the west and bowing around the nosing at the east.

It is not thought that faulting is present in the immediate field.

RESERVOIR ROCKS

The producing portion of the geologic section in the Artesia field must be described as a zone rather than a definite horizon. As will be seen from the accompanying generalized cross section, the producing zones lense in and out laterally, and rise and fall in the section.

In localized areas a producing horizon seems to occupy a definite place in the log, as in Sec. 28, T. 18 S., R. 28 E. A few miles away, as in Section 4, nothing but a small showing is encountered at this place, and the principal "pay" is approximately 350 feet lower in the dolomite. In Section 17 an intermediate condition is found in which the upper horizon produces in one well, the lower in another, and still a third or fourth "stray sand" produces in another.

The producing zone is a portion of the dolomite column in which porous streaks occur. Very little sand is contained in these streaks, although there is some sand in all. With rare exceptions the sand in these streaks constitutes not more than 15 per cent, with a great number of the wells averaging much less than this estimate. The porosity of this zone is thought to be due largely to the solution of inclusions of anhydrite together with the removal of some of the dolomite by the same agency, underground water. There is conclusive evidence of circulation of water in close proximity to the producing zone. The drill has passed through strata both above and below the "pays" in which the dolomite has been honeycombed by solution and in which a considerable amount of travertine has been re-deposited. Large samples of this material have been obtained by the writer when wells have been shot. In a well on the Williams Petroleum Company's lease in Section 17, several hundred feet of oil disappeared from the hole when the drill passed through to one of the honeycombed formations below.

SOURCE ROCKS

Although, as has been stated, the general aspect of the dolomite from which the oil comes is that of a series barren of organic material, there are, nevertheless, sufficient lenses of dark-colored and even lignitic shales to prove that there is a considerable amount of organic detritus in the sediments. It is thought that there are sufficient remains of life in the dolomite and associated shales to account for the origin of the oil.

RELATION OF ACCUMULATION TO STRUCTURE

A study of the accumulation in the Artesia field has led to the conclusion that this is an orthodox case of anticlinal collection, but a condition largely complicated by porosity. This is an example of accumulation on the apex and flank of an anticline. Furthermore, the flank accumulation is on the side toward the regional dip. There is a salt-water line on the eastern side of the producing township.

There are a few anomalies that are prejudicial to this conception. The most productive parts of the field have been Sections 21 and 28. A

glance at the contour map will show that this area lies lower structurally than the production in either Section 17 or Section 4. It is also a fact established by examination of samples that the porosity of the producing zones in Section 28 is higher than that in other parts of the field. It is thought that porosity alone is the explanation for this irregularity. The "Empire pool" will probably be a paying part of the field, but here, too, the porosity is rather high. Therefore it would seem that accumulation in the Artesia field is due to two major factors: (1) proper structural attitude of the formations to arrest migration, and (2) sufficient porosity to provide reservoir space for the migrating oil.

It would seem that the situation of the porous spots on structure is purely a matter of chance since they are found on both the apex and the flank of the anticline.

A well known as the Monita Cronin No. 1 in Sec. 1, T. 18 S., R. 27 E., was higher structurally than Section 4, but it was essentially a dry hole. The Workman *et al.* No. 1 in Sec. 5, T. 18 S.. R. 28 E., much closer, also ran higher than Section 4, and was also a dry hole. Both of these wells have been shown by subsurface work to be on very steep dips (probably $2\frac{1}{2}°$). It is thought that even though there might have been some porosity, accumulation would not have stopped here. At every producing spot in the field there is a flattening of structure to form a terrace. This, then, would also seem to be a prerequisite for accumulation in the Artesia field. The dip across the field is a little more than 100 feet to the mile southeast. The regional southeast dip is less than half this much.

As was mentioned before, salt water is found in the producing zone by low wells east of the field. Oil and gas do not maintain the same ideal relationship as do the oil and water. Wells that make little more than gas are situated irregularly on the structure. Here again it is thought that the degree of porosity is the determining factor. These wells probably find a place in the dolomite where the pore spaces permit the passage of considerable gas but are too fine to permit the formation to give up its oil freely.

MIGRATION

The oil of the Artesia field is thought to have originated in the same general horizon or zone in which it now occurs. This assumption is attested by the fact that wells drilled in a large area around the field, some of them as much as 30 miles east, have appreciable showings of oil and gas at the zone in the section at which the Artesia oil is found. It is thought probable that rather large collection areas and considerable lateral migration are necessary to result in an accumulation of commercial

proportions. It is also thought that this accumulation necessarily required a comparatively long time due to (1) the relatively impervious nature of the reservoir rocks, (2) the large areas contributing to the accumulation, and (3) the small proportion of organic débris in the sediments.

OIL

The oil of the Artesia field is dark brown. It is essentially a paraffin-base oil. The gravity of the oil varies slightly from one part of the field to another, but on the whole maintains a remarkable uniformity.

ANALYSIS OF OIL, ARTESIA FIELD

Mean gravity	37.0° Bé.
Gasoline content (58° Bé.)	40.0 per cent
Sulphur	2.5–3 per cent

GAS

Considerable gas is encountered with the oil. The gas is of such quality that a casing-head gasoline plant has been constructed in the field and connected with 160 wells.

A field compression test showed the average content of the gas to be 1.2 gallons of gasoline per thousand cubic feet of gas.

The field is at present producing approximately 4,000,000 cubic feet of gas.

The rock pressure varies somewhat in the different wells, but ranges from 1,000 to 1,200 pounds per square inch.

PRODUCTION

The first oil was run from the Artesia field in March, 1925. From this time to and including March, 1927, the field has produced 1,896,965 barrels of oil. Approximately 100,000 barrels of this is not shown on run tickets, but was consumed in the field as fuel. At the end of March, 1927, 61 properties were producing, on an average, 6 barrels per well per day from 203 wells. These data include the Artesia field and isolated wells adjacent to the area.

The composite decline curve shown (Fig. 3) represents the monthly average production per well of the field proper, beginning March, 1925. It has been necessary in the construction of the curve to graph lease data separately, combining an estimated average curve for the lease with similarly constructed curves of adjacent properties.

In turn the group curves have been employed likewise in the construction of the master curve. Individual lease curves were indicative of

rather uncertain methods of operation because of the rise and fall of the curve at irregular intervals.

A prediction as to future production for the field has been interpreted from past performance by extrapolation on logarithmic paper. An economic limit of 2 barrels per day per well has been assumed. With this limit the field should have a life of four years.

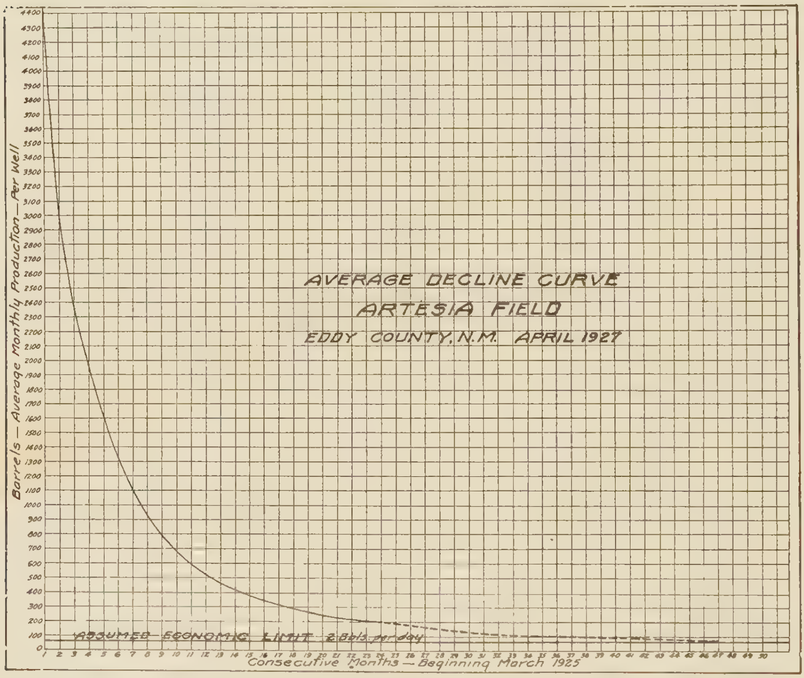


FIG. 3

Every well in the field is shot before being put on production. The usual charge is 100–160 quarts of nitroglycerin. The shot is distributed over the entire zone that has evidenced oil showings. Due to the low porosity of the oil zone, shooting improves the wells greatly.

Due to favorable water conditions, little casing is absolutely necessary. All water is generally passed when the well reaches 600 feet in depth. Many wells are put on production with only one water string in them. In properly operated wells, however, an oil string of casing is usually set 200 to 300 feet above the oil zone.

FUTURE DEVELOPMENT

The immediate area of the Artesia field has been rather thoroughly prospected, but it is entirely possible and even probable that additional pools having somewhat similar relations to the major fold previously described will be discovered. The problem of porosity will be a major factor, but if the coincidence of a porous spot located favorably on structure can be found again, then other producing areas will almost certainly be discovered.

STRUCTURAL CONDITIONS IN PORTIONS OF EASTERN OHIO[1]

KENNETH COTTINGHAM[2]
Columbus, Ohio

ABSTRACT

Regional contour maps are shown on the surface of the Trenton in the western half of Ohio, and on the Berea and Clinton in eastern Ohio. The major structural features are the Cincinnati arch, as expressed by the Trenton, and less conspicuously, the syncline (Parkersburg) and adjacent Cambridge anticline as shown by the Berea in eastern Ohio. Structure contour maps are given for four areas in eastern Ohio. These are for the Berea in southeastern Meigs County and northeastern Muskingum County, for the Berea and shallow sands in the junction of Guernsey, Noble, Belmont, and Monroe counties, and for the Clinton sand in the Homer field of Knox and Licking counties.

The majority of the producing fields of eastern Ohio display some relationship to structure, although the relationship is ideal in but few cases. Structural highs are generally barren, the production lying on the flanks of anticlines or even in the upper ends of synclinal embayments. There is, then, a structural relationship, though not in the stricter sense in which the anticlinal theory was once applied. Most of the oil and gas accumulations are associated with some kind of structural irregularity. As a rule, there is a definite parallelism between the trend of production and the strike of the rocks. In a few places accumulation appears to be entirely a matter of lithology, notably in the Cow Run sand of the Chester Hill field, in Athens, Morgan, and Washington counties. In general, three factors appear to govern accumulation: local structure, water content and energy of movement in the sand, and the porosity of the sand. Since local structure exerts some influence on both water content and artesian conditions in a given sand, structure is regarded by the writer as the dominant factor.

These remarks as to accumulation apply to the Berea and higher sands. The Clinton has long been known as a sand practically devoid of water, although this classification can be accepted only as relative. Because of the lack of reliable key beds, the rapid divergence from surface beds, and the lenticularity of the Clinton, one cannot be sure of structure as mapped for the Clinton. Clinton production appears to be along a transition zone where the sand thins and is replaced on the west by shales.

GENERAL GEOLOGY OF OHIO

The outcropping formations of Ohio range from the Trenton of the Ordovician to the Greene formation of the Permian. The general areal geology of the state is illustrated in Figure 1. The dominant structure is the Cincinnati anticline, which forks in southwestern Ohio, one prong trending northwest through Franklin, Henry, and Howard counties, In-

[1] Presented before the Association at the Tulsa meeting, March 26, 1927.

Manuscript received by the editor, June 13, 1927. Reprinted from *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 9 (September, 1927), pp. 945–58.

[2] Geologist Ohio Fuel Gas Company, 99 North Front Street.

diana, the other extending north by east through Logan, Hancock, and Wood counties, Ohio. Figure 2 shows this fold in Ohio and the productive Trenton area. No production of consequence has been discovered in the Trenton in Ohio outside the shaded area.

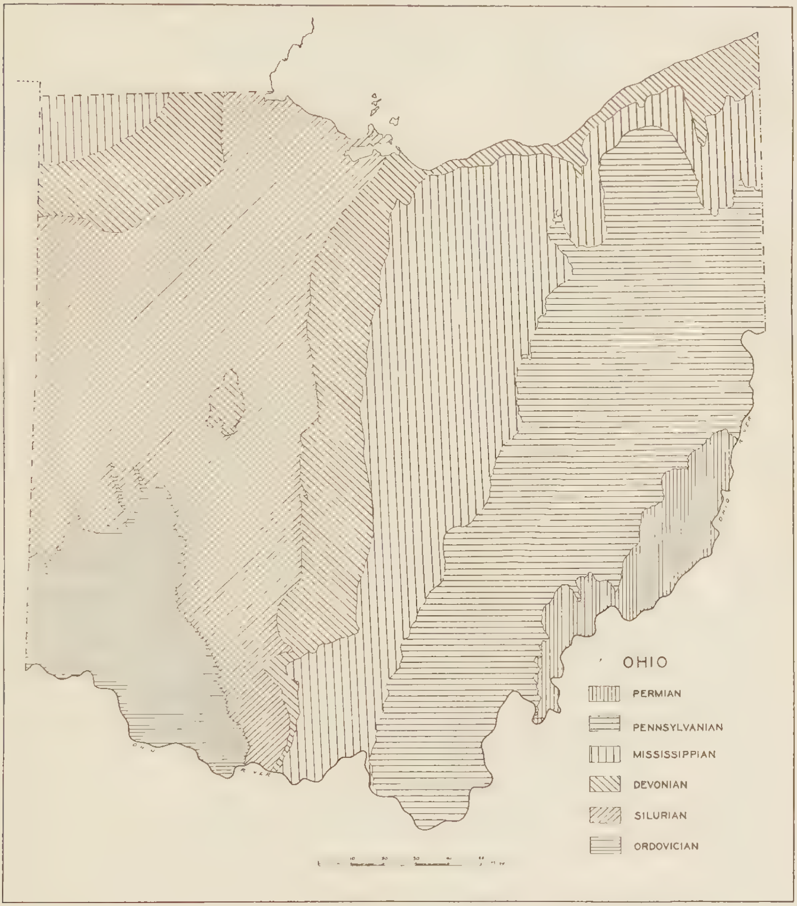


FIG. 1.—Map of Ohio, showing areal geology.

The general structural conditions of eastern Ohio are illustrated by the contour map of the Berea sand (Fig. 3). The Berea lies just above the base of the Mississippian series, and has an average thickness in the wells of eastern Ohio of 20 feet. The maximum thickness known to the writer is 150 feet, reported in a well drilled some years ago at Youngstown, Ma-

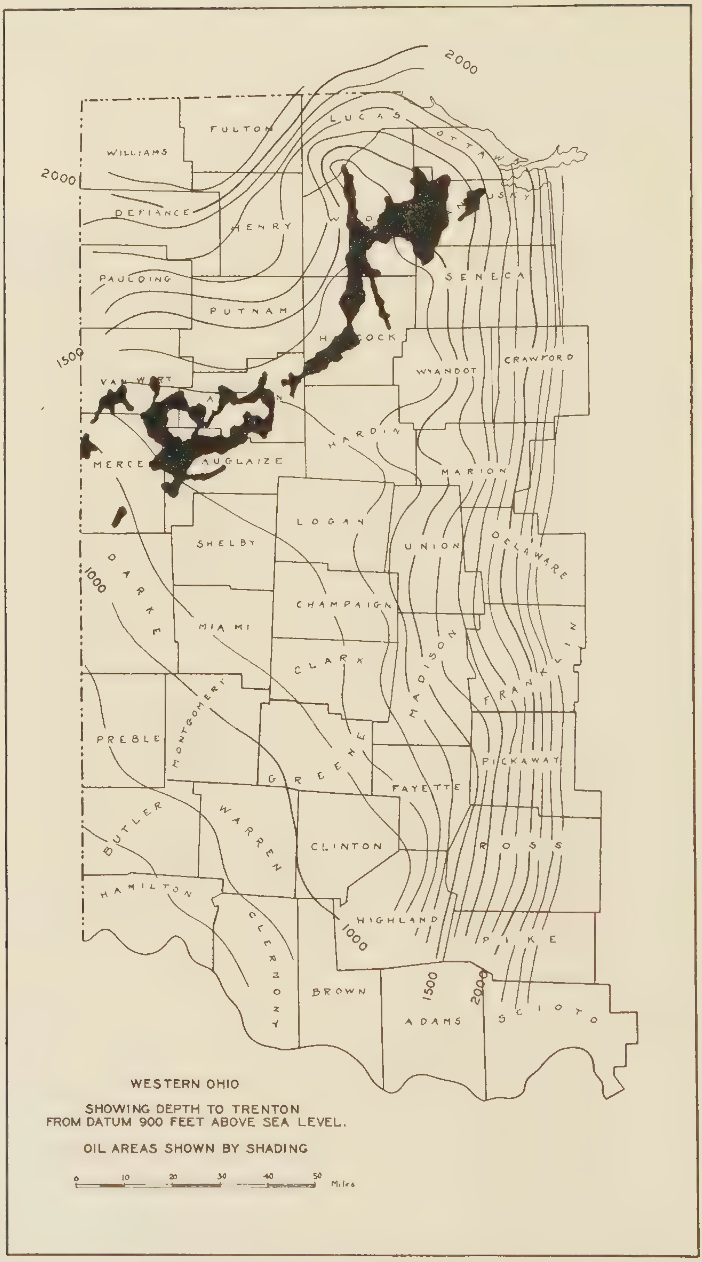


FIG. 2.—Map of western Ohio, showing depth to the Trenton from datum 900 feet above sea-level.

FIG. 3.—Map of eastern Ohio, showing depth to the Berea from datum 900 feet above sea-level.

honing County. The most conspicuous structural feature of eastern Ohio is the syncline extending from Washington County west of north into eastern Muskingum, thence north to western Cuyahoga County. The narrow, sinuous pool (Fig. 3), running from northern Athens County to the

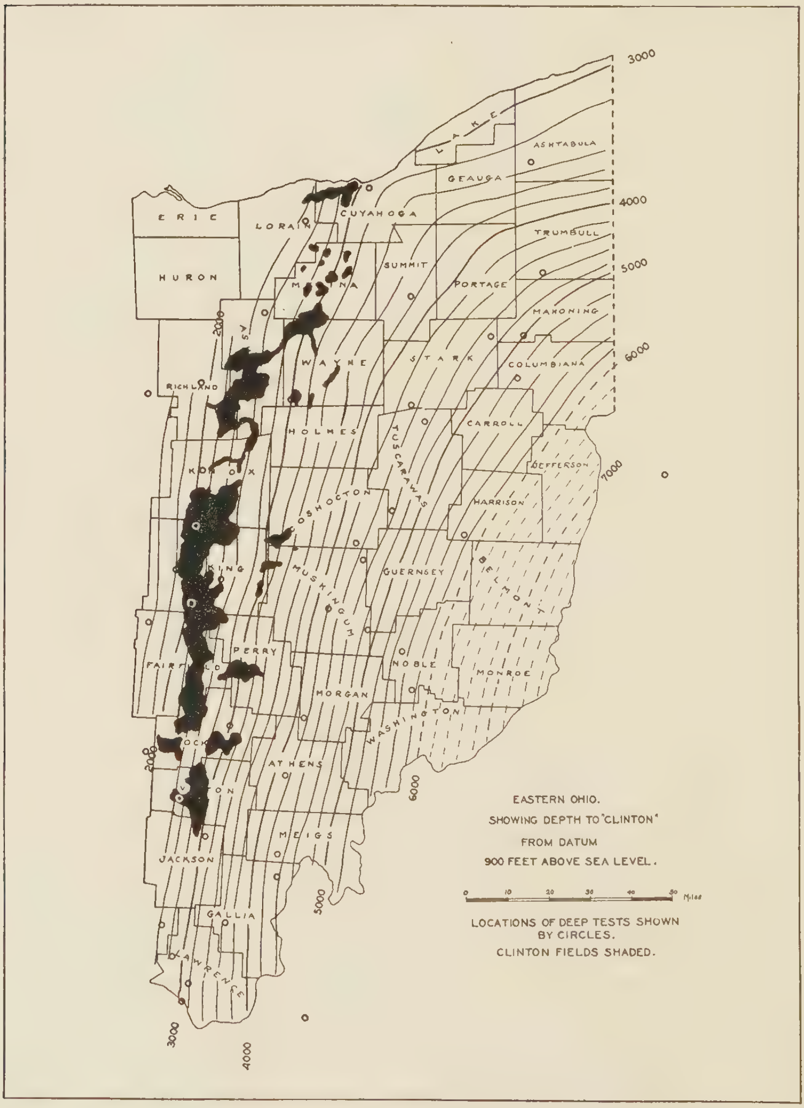


FIG. 4.—Map of eastern Ohio, showing depth to the Clinton from datum 900 feet above sea-level.

Ohio River in south-central Washington County, is in the First Cow Run sand. The accumulation in this pool is in a coarse, conglomeratic sand probably representing a buried stream channel.

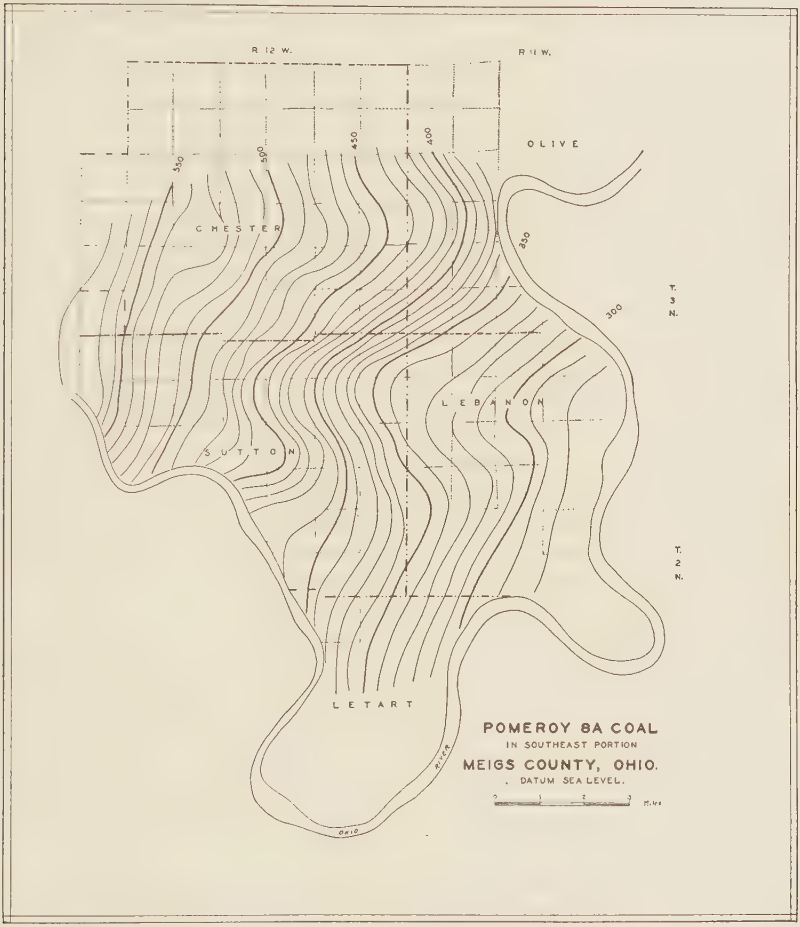


FIG. 5

Reference to Figure 4 will show that the structural features of the Berea are almost effaced in the Clinton, due to the eastward expansion of the Devonian shales and Devonian and Silurian limestones.[1] The Berea-Clinton interval in central Ohio is 1,400 feet. In eastern Monroe County it has increased to probably 5,400 feet.

[1] Cottingham, *National Petrol. News* (August 11, 1926), p. 45.

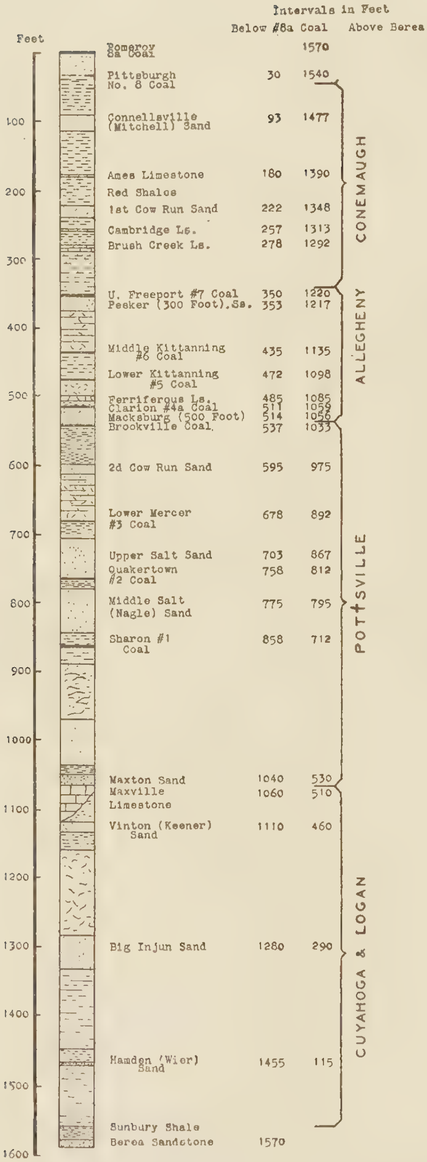


FIG. 6.—Composite geologic section from the Pomeroy coal to the Berea sandstone, southeastern Meigs County, Ohio.

SOUTHEASTERN MEIGS COUNTY

The attitude of the Pomeroy (8*a*) coal in Chester, Olive, Sutton, and Lebanon townships is shown in Figure 5. The Pomeroy coal, lying 30 feet higher than the Pittsburgh coal (the latter is absent throughout the area), is mined in the western part of Chester and Sutton townships. A composite section for this region from the Pomeroy coal to the Berea is shown in Figure 6.

The structure of the Berea sand is shown in Figure 7. Allowing for the fact that the contour interval is different in the two maps, being 10 feet for the Pomeroy coal and 20 feet for the Berea, it will be noticed that the Berea structure is somewhat different from the surface structure and more moderate. Because of the eastward expansion of intervals, all minor structures of eastern Ohio become less pronounced with depth. In the area mapped here, the interval from the Pomeroy coal to the Berea ranges from 1,530 to 1,700 feet, increasing in general southeastward. The divergence, however, is not regular. There is a notable increase in eastern Chester Township. The consequent thickening of the vertical section occurs in the sandstones between the Sharon coal and the Maxville limestone.

The oil and gas field in Sutton Township was opened in the summer of 1923. The average oil well had an initial yield varying from 15

to 20 barrels. The best gas wells were found on the crest of the nose in Sutton Township (on the map, just below the letter *O* in Sutton). The largest of these had an initial open flow of 5,000,000 cubic feet. The "pay" is generally in the upper 5 feet of sand.

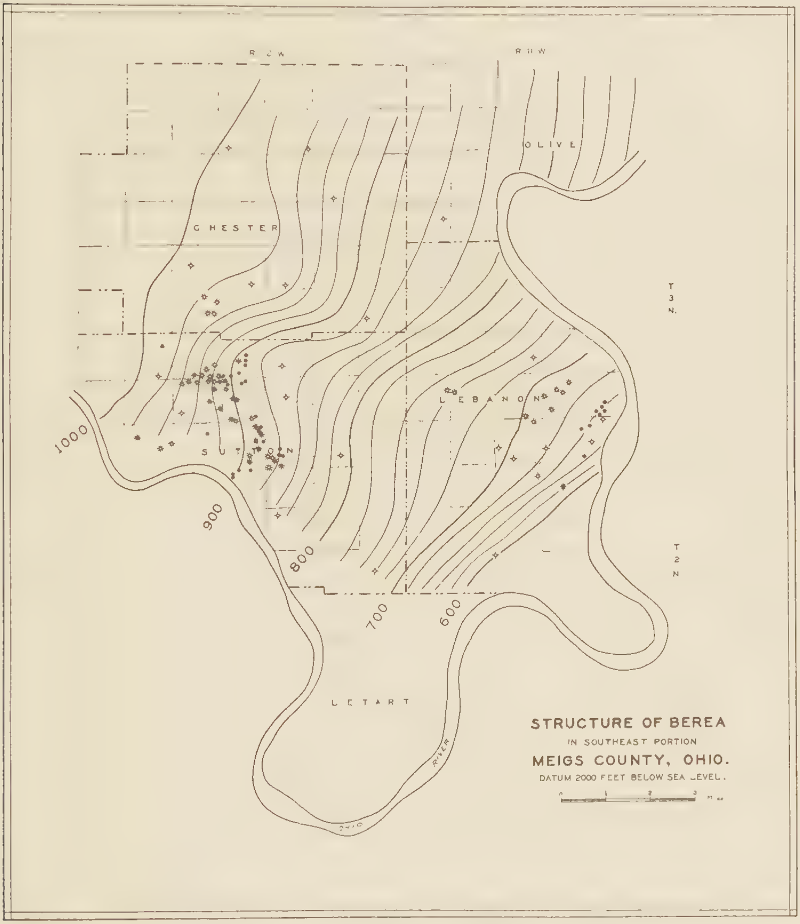


FIG. 7

The pool in Lebanon Township is older. The initial yields of the wells there were less, the initial open flow of the largest gas well being 600,000 cubic feet, and the average 300,000. Several of the dry holes in Lebanon Township showed as little as 2 feet of Berea sand. The sand invariably contains water, generally a few feet below the top.

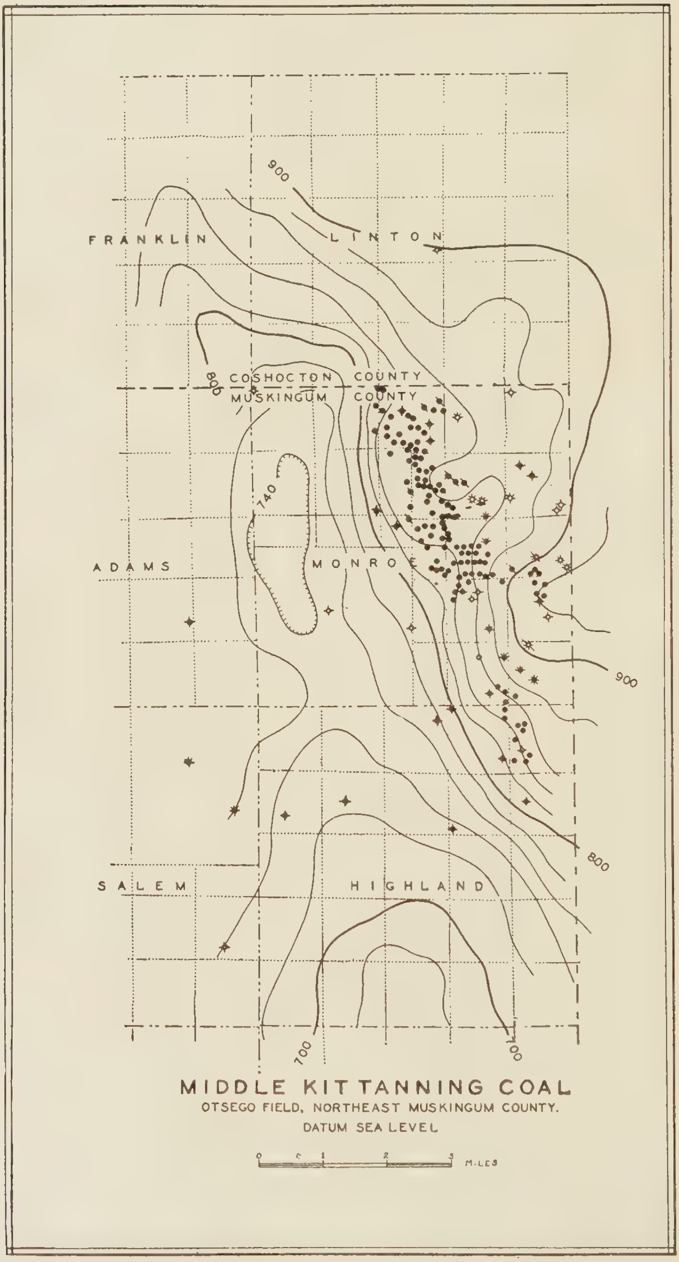

FRANKLIN
LINTON
900
800
COSHOCTON COUNTY
MUSKINGUM COUNTY
740
ADAMS
MONROE
900
800
SALEM
HIGHLAND
700
700
MIDDLE KITTANNING COAL
OTSEGO FIELD, NORTHEAST MUSKINGUM COUNTY.
DATUM SEA LEVEL
MILES

FIG. 8

NORTHEAST MUSKINGUM COUNTY

The Berea pool in Monroe and Highland townships, Muskingum County (Fig. 8), was opened about 1903. The initial production of the largest wells was 35 barrels; the average was about 10 barrels. The oil is found in the lower part of the Berea, as a rule with more or less salt water. The quantity of salt water increases greatly in the syncline.

The interval from the Middle Kittanning coal to the Berea is 985 feet and is constant. Two holes were drilled to the Clinton in Monroe Township, one in the extreme northwestern corner of the township, the other two miles south of the northeast corner and just west of the township line. Both were dry in the Clinton.

This pool lies on the west flank of the Cambridge anticline, as brought out in a general way in the Berea map of eastern Ohio (Fig. 3). The recently discovered Cambridge gas field lies about seven miles southeast. The gas in this latter field is found about 120 feet in the "Niagara" lime, from a sand which many have regarded as correlative with the Oriskany.

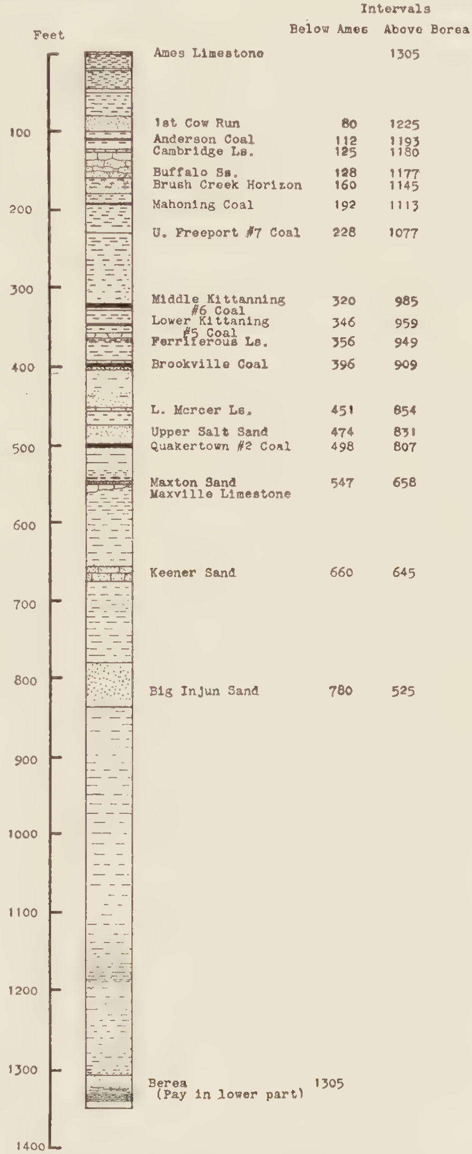


FIG. 9.—Geologic section from the Ames limestone to the Berea sandstone, northeastern Muskingum County, Ohio.

The interval from the Berea to the Clinton in the area mapped ranges from 3,000 feet on the western side to 3,400 feet along the eastern line.

GUERNSEY, NOBLE, BELMONT, AND MONROE COUNTIES

The attitude of the Pittsburgh coal as shown in Figure 10 is taken from *U. S. Geological Survey Bulletin 720.* Although there is some irregu-

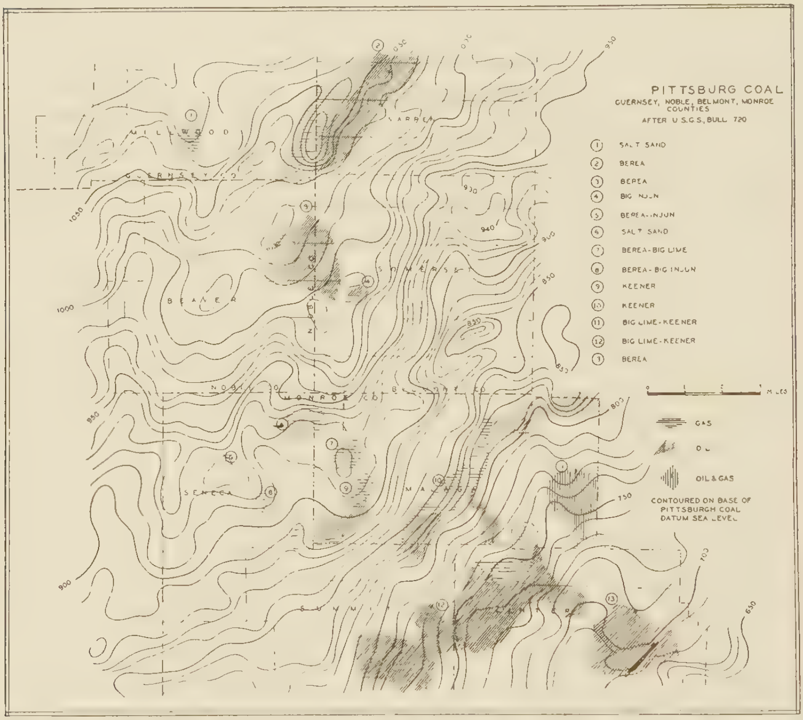


FIG. 10.—Map showing structure of the base of the Pittsburg coal above sea-level, Guernsey, Noble, Belmont, and Monroe counties, Ohio.

larity in the Pittsburgh-Berea interval, it is not great enough in the area shown here to make any vital difference between the surface and the Berea structure. The Berea lies about 1,570 feet below the Pittsburgh coal. It has a thickness as little as 3 feet and as great as 40 feet, though the average is about 20 feet. The position of the "pay" in the Berea differs considerably. In the area shown here, it is in the upper part of the sand.

To the depth of the Berea and including it, there are about twelve sands, at least half of them being important as the source of oil or gas. In

several places oil is yielded by sands at points only a few miles east of the outcrop. All of the sands contain water in varying amounts.

The area east of the Cambridge anticline, of which this is a portion, is in general an area of small, irregular folds. The structural arrangement, though not particularly complex, is probably as much so as any part of eastern Ohio. Of the pools shown in the figure, at least eight show a direct relationship to structure.

The first wells drilled in the Barnesville field (No. 2, Fig. 10), were two gas wells completed about 1890, the first of which had an initial open flow of 750,000 cubic feet and a rock pressure of 640 pounds. The first oil well in this field produced 25 barrels a day. In the Temperanceville field (No. 3), oil was discovered in 1899, and the initial production of the first well was 17 barrels. Both of these fields are Berea. The oil ranges in gravity from 42° Bé. in the Temperanceville field to 46° Bé. in the Barnesville field.

KNOX AND LICKING COUNTIES

HOMER GAS FIELD

The Homer gas field (Fig. 11) was one of the most prolific fields in Ohio, though well on the way to depletion to-day. The discovery well was completed in 1900; the initial open flow was slightly more than 1,000,000 cubic feet, and the initial rock pressure 700 or 800 pounds. The average thickness of the Clinton is 18 feet. The largest wells were found in Miller and Morgan townships, the largest having an initial open flow ranging from 8,000,000 to 12,000,000 cubic feet.

Practically the entire area shown on the map yielded Clinton gas, though there were a few dry holes and light producers. The scale of the map makes it impossible to locate all wells. The western limit of Clinton production is indicated by shading, west of which the Clinton sand is replaced by red shales.

Although the Clinton is known as a water-dry sand, that classification is only relative. As Johnson[1] and others have pointed out, the absence of connate water would require a combination of circumstances hardly possible of fulfilment.

EFFECT OF STRUCTURE ON ACCUMULATION

BEREA SAND

Though there are no figures at hand on the matter, the writer would hazard the opinion that 65 per cent of the shallow-sand production in Ohio, including the Berea, has some structural basis. The Clinton is not

[1] *Trans. Amer. Inst. Min. Eng.*, Vol. 51 (1916), p. 587.

included. It is a common occurrence in wells drilled on the crest of domes or other strong types of anticlines to find hard, or broken, or thin sand devoid of gas or oil. In the aggregate, far more oil has been produced from

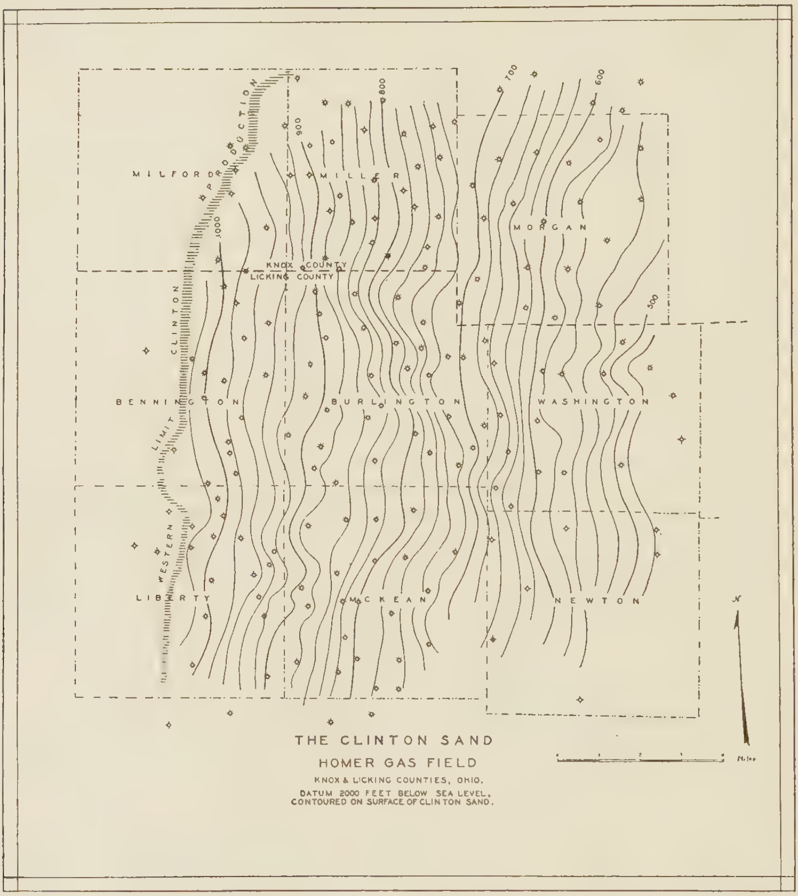


FIG. 11.—Map showing the structure on the surface of the Clinton sand above datum 2,000 feet below sea-level, Knox and Licking counties, Ohio.

the Berea on low noses, low on the flanks of folds, and in shallow synclines, than on the crest of domes or folds. Many Berea pools are at the upper end of a structural embayment.[1] Porosity alone can hardly account for these cases because they are too frequently associated with the same type of minor structure. Presumably artesian conditions prevail in the

[1] D. Dale Condit, *U. S. Geol. Survey Bull. 541-A.*

shallow sands, the water movement being toward the west and northwest or away from the hydraulic head along the Appalachian Plateau. The hydraulic gradient is low, and many of the sands are persistently fine grained, as a result of which water movement is slow. It would seem possible that disseminated oil is carried by circulating water to a point where the velocity of movement is reduced.[1] The fact that so many pools are found where there is some structural irregularity suggests that structure is a dominating factor.

THE CLINTON SAND

For all practical purposes the Clinton can probably be regarded as a water-dry sand, though there are places in Ohio, notably parts of Jackson and Vinton counties, where it does contain water. In the producing areas, the Clinton is a series of lenses. Consequently, in a map such as Figure 11, one cannot be positive, in working from well records, how much is real structure. In any event, whatever structure there may be in the Clinton in most of Ohio, it is nothing more than irregular terracing. There is some evidence, locally, that the volume of Clinton wells is greater along terrace fronts. The theory has been held that since the Clinton contains so little water, Clinton oil pools are synclinal. The writer has never seen anything to support the latter theory. In this connection it might be noticed that two deep Clinton tests were made in the prominent syncline in eastern Ohio shown in Figures 3 and 8. Both were located directly in the syncline as expressed by surface formations, and both were dry. Another deep test in western Guernsey County, and on the Cambridge anticline, found 100 feet of Clinton sand, but was also dry.

The older view, that the Clinton pools occur where the sand feathers out and is replaced by shale, goes as far in explanation as any. Possibly when deeper drilling is warranted another series of similar lenses may be found farther east.

[1] J. L. Rich, *Econ. Geol.*, Vol. 16, No. 6, p. 347.

GENERAL STRUCTURE OF THE PRODUCING SANDS IN EASTERN OHIO[1]

J. R. LOCKETT[2]
Cleveland, Ohio

ABSTRACT

The producing fields of eastern Ohio lie along the west side of the Appalachian syncline where the normal southeast dip is broken by the minor structures which resulted from the Appalachian folding.

The most important structural feature is the broad northern development of the Burning Springs–Volcano anticline which is paralleled on the west by the deep Parkersburg syncline. This general uplift has a width ranging from 25 to 30 miles, and extends about 80 miles northeastward into Ohio from West Virginia.

Twelve shallow sands occur in the Pennsylvanian and Mississippian systems, and two deeper sands have been extensively developed.

The most consistent shallow sand accumulation has been along the general anticlinal structure, and is controlled by local structure, generally lacking any definite trend.

Geological work on the Pennsylvanian and Mississippian sands has been generally successful, but the interpolation of the structure of the deeper sands which lie in the Devonian and Silurian is made more difficult by the rapid eastward expansion of these two systems.

The Cambridge gas sand, which occurs near the base of the Devonian, has been extensively drilled in eastern Guernsey County, where the sharp reversal caused by the Parkersburg syncline is sufficient to overcome the westward convergence of the upper Devonian shales. If this sand is present along the entire length of this uplift, new fields may be discovered in the direction of Parkersburg. East of Guernsey County the dip is too sharp and the convergence too great to be overcome by such reversals as exist.

The Clinton sandstone, near the base of the Silurian, is the deepest producing horizon in eastern Ohio. From a heavy quartzose bed in the extreme eastern part of the state it pinches westward into isolated lenses, in the more porous of which the production occurs. This sand is absolutely devoid of water, which feature, together with the lenticular nature of the reservoirs, renders extensive geological work impractical.

GENERAL STATEMENT

Structural conditions in parts of eastern Ohio have been described in detail by the state and government surveys,[3] which work has been chiefly

[1] Presented before the Association at the Tulsa meeting, March 26, 1927. Reprinted from *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 10 (October, 1927), pp. 1023–33.

[2] The East Ohio Gas Company, 1405 E. Sixth St. Introduced by Sidney Powers.

[3] W. T. Griswold, "The Berea Grit Oil Sand in the Cadiz Quadrangle, Ohio," *U. S. Geol. Survey Bull. 198*, 1902; "Structure of the Berea Oil Sand in the Flushing Quadrangle," *U. S. Geol. Survey Bull. 346*, 1908. D. D. Condit, "Oil and Gas in the Northern Part of the Cadiz Quadrangle," *U. S. Geol. Survey Bull. 541-A*, 1913. C. A. Bonine, "Anticlines in the Clinton Sand near Wooster, Wayne County, Ohio," *U. S. Geol. Survey Bull. 621-H*, 1915. D. D. Condit, "Structure of the Berea Oil Sand in the Woodsfield Quadrangle," "Structure of the Berea Oil Sand in the Summerfield Quadrangle," *U. S. Geol. Survey Bull. 621-O* and *621-N*, 1916.

for the purpose of ascertaining the possibilities and limitations of geological work in the development of oil and gas and to furnish maps and data which would serve as criteria to those operators who wished to study other areas in a similar way. Although thousands of wells have been drilled, and the entire eastern half of the state studied by geologists, an authentic structure map of the entire area will probably not be available for several years and it has been impossible to publish such connected data as would be of value to those unacquainted with these fields. It is the purpose of the writer to describe the producing sands of eastern Ohio and the structural features influencing accumulation in a general, rather than a local way, giving information which will be of interest to those who contemplate further development in that section.

GENERAL STRUCTURE AND STRATIGRAPHY

From the crest of the Cincinnati arch in western Ohio the beds dip into the Appalachian trough in Pennsylvania and West Virginia. The axes of both anticline and syncline extend northeast and southwest, but that of the syncline inclines somewhat more to the east. The northern and more shallow part of the trough, therefore, is relatively farther east, and as a result there is practically no east dip across the northeast part of Ohio. In that section of the state the dip is principally southward, under the influence of the beds which dip southeast into the deeper part of the syncline. The structure of the eastern half of the state is therefore comparable to one quarter of a bowl. The general direction of dip is southeast, and the average rate of dip is 35 feet to the mile.

The beds exposed at the surface in this part of the state are, from west to east, of Mississippian, Pennsylvanian, and Permian age. At least twelve sands occur in the Pennsylvanian and Mississippian, one near the base of the Devonian and one near the base of the Silurian. These horizons will be described more fully in a following section.

The only unconformity of any consequence is that at the base of the Pennsylvanian. Although in some places the relief in the upper Mississippian is as great as 200 feet, the beds above and below this zone lie practically parallel, and the Berea sand, at the base of the Mississippian, conforms reasonably well with the surface structure. The greatest difficulty arising from this unconformity is that of mapping the surface beds along its outcrop from Scioto to Holmes County. The basal members of the Pennsylvanian, including several coals frequently used as reference benches, were deposited in basins in Mississippian topography. Correlation in many places is difficult, and many false structures have been mapped in this area.

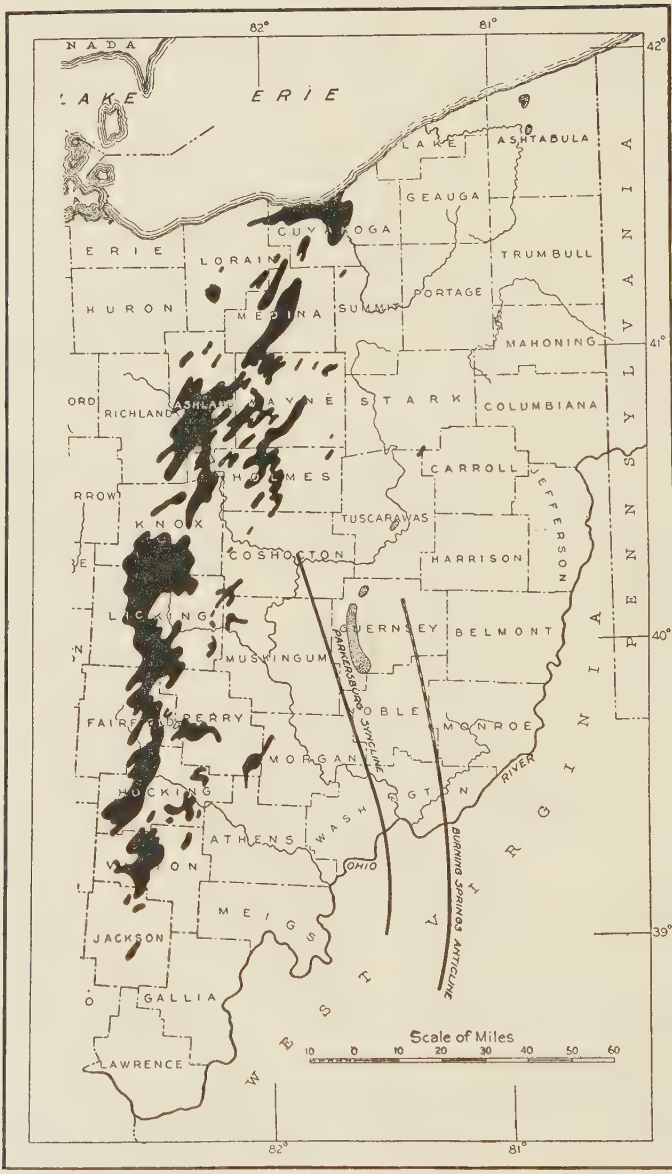


FIG. 1.—Map of eastern Ohio showing the "Clinton sand" fields and the Cambridge gas field in Guernsey County.

The most important factor to be considered in interpolating the structure of beds lying below the top of the Devonian is the rapid eastward expansion of the Devonian and Silurian systems, which comprise the Bedford and Ohio shales of the Upper Devonian and a great series of Devonian and Silurian limestones and dolomites known among operators as "The Big lime." This expansion is given by Stout[1] as 35 feet to the mile eastward, and 0.74 foot to the mile southward. More recently drilling east of the territory plotted by Stout indicates that the rate of thickening increases in that direction to at least 50 feet to the mile in Harrison and Columbiana counties.

The normal southeast dip is broken by local structures which are the most western results of the Appalachian folding. There are hundreds of low rolling anticlines and shallow synclines which increase in magnitude toward the south and east. Many of these structures have been proved to be the controlling factors in shallow sand accumulation, although as many more which looked as promising when mapped have been dry. Owing to the lack of systematic and connected work in any considerable area, the controlling influence of two major structural features has not been recognized. These are the Parkersburg syncline and the Burning Springs-Volcano anticline, which have been mapped by the West Virginia Survey.[2]

The Parkersburg syncline crosses Ohio River between Parkersburg and Marietta and extends northwest at least 80 miles. The axis can be plotted through central Washington County, the southwest and northwest corners of Noble County, the southwestern edge of Guernsey County, crossing about the center of the Muskingum-Guernsey county line and extending northwest into central Coshocton County.

East of this syncline in West Virginia the beds rise abruptly in the Burning Springs anticline and then drop toward the southeast in a succession of anticlines and synclines. The Burning Springs anticline extends into Ohio, broadening out considerably in its northern development. Its axis parallels that of the Parkersburg syncline.[3] The depth of the syncline in Ohio is, on the average, 150–200 feet, and the influence of the Burning Springs anticline can be seen in the fact that 25 miles east of the southwest corner of Noble County the surface beds are only 100 feet lower than in the deepest part of the trough. Thirty miles east of the northwest corner

[1] Wilbur Stout, *Geol. Survey of Ohio, Bull. 21* (1918), pp. 287–88.

[2] G. P. Grimsley, *West Virginia Geol. Survey*, 1910.

[3] The importance of these two features was first pointed out by Wilbur Stout, assistant state geologist of Ohio.

of Noble County they lie 75 feet lower, and 30 miles east of the Muskingum-Guernsey county line they have dropped only 75 feet.

Many fields producing from all sands above the Silurian lie along this general uplift. The accumulation is a result of the general anticlinal structure, but is further controlled by sand conditions and by the local structure which in any restricted area will be found to be a series of noses, terraces, and troughs, as a rule lacking any general trend. It is necessary for the geologist to work out this series in detail before the sands are tested.

East of this general uplift, approaching Ohio River, the beds drop off more sharply and the local structures assume proportions more comparable with true Pennsylvania and West Virginia conditions. There is in more places a logical northeast-southwest trend, the general structure being similar to that in West Virginia east of the Burning Springs anticline.

The shallower sands produce as far west as a line between Knox and Lawrence counties. West of the Parkersburg syncline, however, the dip is sharper and there has been less folding. As a result, the shallow fields are more patchy, and their production is relatively smaller.

SANDS

Among operators in southeastern Ohio the principal reference bench is the Pittsburgh or No. 8 coal which lies at the base of the Monongahela formation of the Pennsylvanian. It is one of the heaviest and most easily recognized of the coal beds in the state, and is sufficiently near the surface, from its outcrop to Ohio River, to serve as a guide in correlating the Pennsylvanian and Mississippian sands. Twelve producing sands occur in these two systems, the names of which, together with their average depths below the Pittsburgh coal, are as follows:

PENNSYLVANIAN AND MISSISSIPPIAN SANDS WITH DEPTHS BELOW PITTSBURGH COAL

Sand	Depth in Feet	Sand	Depth in Feet
First Cow Run	300	Maxton	950
Buell Run	350	"Big lime"	975
Peeker	525	Keener	1,060
Macksburg	650	Big Injun	1,100
Second Cow Run	700	Squaw	1,200
Salt sand	750	Berea	1,600

The most dependable of these are the Salt sand, Keener, Big Injun, and Berea.

The Salt sand is a group of coarse-grained sandstones, in many places interbedded with shales, generally about 100 feet thick. It lies in the upper part of the Pottsville formation, and its structure follows very regularly that of the surface beds. Although it generally carries much water, in many salient structural conditions it produces gas. It rarely produces oil.

The Maxton or Lower Salt sand is the Sharon conglomerate, and marks the base of the Pennsylvanian system. It is lenticular and generally thin, and from the nature of its deposition on an eroded land surface, it is very inconsistent in structure and continuity.

"The Big lime" of the shallow fields is the Maxville limestone, which is the highest member of the Mississippian. It consists of thin-bedded limestones interbedded with sandy layers in which the production occurs. Although its thickness is in places as great as 100 feet, it is very lenticular and unreliable. Its structure is more regular than that of the Maxton sand, but its presence is dependent on Mississippian topography. Very few wells are drilled on the possibility of "lime" production alone, but many in Belmont and Monroe counties produce from this horizon.

The Keener sand occurs immediately or very close below the Maxville limestone. It is formed of alternating beds of fine- and coarse-grained sandstone, and in many places carries considerable water. The average thickness is 30 feet. It is much more uniform than either the Maxton or Maxville, and the production follows the general structure more consistently than in any other of the shallower sands.

The Injun sand is very regular in its occurrence, but very erratic in its thickness, which may range from 50 to 200 feet. It is coarse-textured and contains some beds of a conglomeratic nature. It is interbedded with thin shales. Cross sections indicate that the variation in thickness is at the base, which is probably a result of channels cut in the soft Mississippian shales by the coarse sand. The top follows the general structure more regularly than would be expected for a sand of such variable thickness, but it carries much water and is productive in few places except on the most prominent structural elevations. It may be full of water on lower anticlines where the Keener is productive. As the two sands are separated by only a few feet of shale, many good Keener wells have been ruined by drilling into Injun water, although in the higher parts of some structures, where the Keener produces gas, the Injun may produce oil.

The Squaw sand, which may be encountered from 20 to 40 feet below the Injun, is very erratic. It occurs as long narrow lenses which generally have a northeast-southwest trend and are evidently Mississippian sand bars. These beds have little relation to the general structure and are

generally water-bearing. The Squaw sand has produced some high-grade oil, particularly in Columbiana County, but the accumulation is limited by the lenticular nature of the sand. Although detailed subsurface mapping has been of value after a field has been partially drilled, there is little hope of discovering new fields in this sand on geological advice.

The Berea is the most important shallow sand in Ohio, and produces in scattered fields from Medina County south and east into Kentucky, West Virginia, and Pennsylvania. Its thickness ranges from 10 to 100 feet, the average in the producing areas being about 35 feet. As a rule it is fine-grained and light colored and contains erratic lenses of coarser sand in which the heavier oil and gas "pays" are encountered. In places it is interbedded with shales, and it may be represented only by sandy shale. In other places, particularly in Columbiana, Carroll, Jefferson, Gallia, and Meigs counties, it occurs as two distinct beds separated by 1 to 30 feet of shale. In the western fields, which are farther from the source of the sediments, few coarser-grained beds are encountered, and the natural production of the wells is seldom encouraging. After they are shot, however, both oil and gas wells in this territory are exceptionally long-lived.

The Berea lies at the base of the Waverly formation of the Mississippian, which is somewhat variable in thickness. Its structure follows in a general way that of the surface beds, but differs locally as much as 75 feet. In northern Jefferson and Columbiana counties, due to a thinning of the Waverly, the Berea lies almost 400 feet higher in its relation to the surface beds than in Tuscarawas County.

In most places this sand is water-bearing. Although the production follows, in general, anticlinal and terraced structures, the accumulation is locally dependent on the porosity and continuity of the sand. Many dry holes have been drilled where structural conditions were most favorable.

In many places in the southern part of the state a thin sand called the Welsh Stray, which may be correlative with the Wier sand of West Virginia, is encountered from 60 to 70 feet above the Berea. In appearance it is not unlike the Berea. It is generally dry, and it is quite possible that many outlying dry holes in southern Ohio which were supposedly drilled through the Berea were in reality only drilled through this "stray" sand. The real Berea sand can be identified anywhere by the presence of at least a few feet of the very black Sunbury shale which lies immediately above the sand.

Below the Berea lie the Ohio shales of the Upper Devonian which, as previously mentioned, thicken rapidly eastward. In New York, Pennsylvania, and West Virginia, the formation contains several producing

sands which thin out and disappear toward the west. In northeastern Ohio, gas production of commercial value is encountered in some of these shales. This has been called shale gas, and is thought to come from crevices in the shale. In reality it occurs in sandy streaks which are outlying patches of the heavier eastern sands. Geological work on these sands has been attempted, but correlation has never been successful. They are too lenticular, and the production ordinarily too small, to warrant geological consideration.

In western Guernsey County, on the large anticlinal structure which lies immediately east of the Parkersburg syncline, exceptionally good gas production, with some oil, has been found in a sandy horizon near the base of the Devonian. This sand has not as yet been correlated, but is thought to be a western development of the Oriskany of Pennsylvania. It lies from 115 to 165 feet below the top of the series of Devonian and Silurian limestones and dolomites which is also known as "the Big lime." In few places is it encountered west of Guernsey County, and it does not crop out in the central part of the state.

A consistent water horizon occurs from 200 to 300 feet below the top of this group of limestones throughout practically the whole east half of the state. At this horizon several small gas fields have been developed in the so-called "Austinburg sand" in Ashtabula County. Two sandy water-bearing strata have been drilled through in the upper part of the "Big lime" both east and west of the Guernsey County field. At this time no definite correlation can be made, but it appears that the upper of these is the Guernsey County gas sand, possibly the Oriskany; and the lower is the general water-bearing horizon and also the Austinburg sand of Ashtabula County.

Even when the structural distortion resulting from the westward convergence of the Ohio shales is taken into account, it is still apparent that this accumulation is controlled by the anticlinal structure, as a west dip of more than 100 feet in the surface beds amounts to at least 40 feet in the sand. East of this field the top of "the Big lime" drops 50 feet to the mile. Very few anticlines within practical drilling depth have sufficient reversal to warrant the plotting of more than a terrace at the producing horizon. The comparatively high water level in the well-developed Guernsey County structure makes the possibility of similar fields on the east appear doubtful.

The logical supposition is that if more fields are to be discovered in this sand they will lie along the uplift paralleling the Parkersburg syncline, where conditions are comparable with those in the Guernsey County field.

The so-called "Clinton" sandstone is by far the most important source

of oil and gas in eastern Ohio. Although it has been drilled extensively from Lake Erie on the north to Jackson County on the south, and drilling and operating conditions are well understood, less definite geological information is available on this sand than on any other producing horizon in the state.

When first discovered, this sandstone was thought to be the equivalent of the Clinton limestone of the Lower Silurian, and was so named. Its exact location in the geological column is not yet determined. It appears that the name "Clinton" is a misnomer, and that this sand, together with the shales with which it is interbedded, should be considered either as a distinct formation of the Oswegan series or as a separate member of the Medina formation, which lies at the base of the Silurian system.

It was deposited from the southeast as a heavy sand which becomes lenticular and disappears before the Lower Silurian beds outcrop in western Ohio. In the southeast quarter of the state, in the area east of the Parkersburg syncline, the thickness averages about 100 feet; but the depth is too great for practical operation and the bed is of a quartzose nature, having practically no porosity.

The producing fields lie farther west, where the sand is lenticular and unreliable. The depth in Huron County is about 1,500 feet, and the deepest producing wells have been in Stark County, at a depth of more than 5,000 feet.

It is everywhere hard and close-grained, and although in many places of a reddish color, the best production is found in light gray or white sand. It generally occurs as a series of lenses interbedded with gray or red shales, and probably represents both continental and shallow-water deposits.

In places the Clinton undoubtedly conforms to the general structure, but as the sand contains no water and the accumulation is confined to lenticular reservoirs, the general structure is of little consequence in the search for new fields.

Many subsurface maps show abnormal structure in the Clinton sand. These maps are generally misleading, as there is no way to represent the actual condition by contours. The Clinton horizon constitutes the interval from 75 to 150 feet between the "Little lime," probably the true Clinton, and the Red Medina shales. As many as four lenses of sandstone may be encountered in this distance, or the sand may be absent. Maps showing the producing wells in a field do not indicate the extent of any particular sand body. The lenses differ greatly in extent, and generally overlap. Few are more than half a mile wide, and many only a few hundred yards. Intersecting cross sections and peg models show that the

accumulation follows logically the depositional structure, each lens in a producing area containing gas under a different pressure, or a separate accumulation of oil, and in places both. The gas occurs in the higher part of a lens, and where the sand is continuous in a sufficient area, considerable oil has collected in the lower parts of larger lenses. The lower limits of smaller lenses are generally marked by showings of oil in gas wells or by small oil wells.

The evident impossibility of a widespread migration of oil and gas through such a horizon and the existence of extensive barren areas where sand conditions seem favorable suggest that the origin of the oil and gas contained in the Clinton has been connected with lines of deformation coincident with the producing areas. If this is true, the deformation has been too slight in many places to be recognized in the surface beds, although drilling to the Clinton on well-defined structures in outlying territory has been generally unsuccessful.

When the entire producing area of the state is plotted, the decided northeast-southwest trend of the individual fields is apparent. This is more probably a result of similar depositional conditions than of folding.

Detailed subsurface work, confined to local problems, has been of considerable value in extending existing fields, but as yet very few new fields have been discovered on geological advice.

CONCLUSION

The fields of eastern Ohio lie on the western edge of the great Appalachian district. The entire territory has been drilled to some extent, but there has been little systematic development. Their production is relatively less than that of the Pennsylvania and West Virginia fields, but the oil produced is of the highest grades, and there is a ready market for gas. When all factors are considered, the opportunity for return on the same investment is as great as in parts of the country where heavier production might be obtained.

Geological conditions in the shallower sands, so far as they are understood, are similar to those in the eastern fields, where detailed geological work has been of great value. The Ohio sands were deposited farther from the source of the sediments, and as a result are more lenticular. Deformational structure cannot be considered as entirely the controlling influence in accumulation. In almost any locality in Ohio there has been sufficient drilling to enable the geologist to supplement the study of surface structure with comprehensive subsurface information.

There is every reason to believe that, with systematic geological work, many new fields will be discovered.

MORRISON FIELD, PAWNEE COUNTY, OKLAHOMA[1]

EVERETT CARPENTER
Bartlesville, Oklahoma

ABSTRACT

The Morrison field of Pawnee County, Oklahoma, is southeast of, and closely related to, the Kay County district in structure and producing horizons. Surface anticlinal structure is readily mapped on the Fort Riley limestone of Permian age. Subsurface structure is generally similar to the surface, and is mapped on the Tonkawa sand, Layton sand, and "Mississippi lime" of Pennsylvanian age, and the "Wilcox" sand of pre-Pennsylvanian. The amount of closure increases with depth, amounting to about 150 feet on the "Wilcox" sand. Depth of producing sands ranges from about 2,000 to 3,800 feet. The total production of the field by the end of 1926 was 4,566,800 barrels of oil, or more than 11,000 barrels per acre.

LOCATION

The Morrison field is located in T. 22 and 23 N., R. 3 E., Pawnee County, Oklahoma. It lies southeast of the Kay County district, with which it is closely related as regards structure and producing horizons. It has a producing area of only about 320 acres, but had produced 4,566,800 barrels of oil up to the close of 1926.

HISTORY

The history of the Morrison field commences with the year 1915. The structure was discovered in January of that year by Frank Buttram, who was then employed by the Fortuna Oil Company. The first well, George L. Miller No. 1, was completed by Robert Watchorn on December 27, 1915, as a 35,000,000-cubic foot gas well in the Tonkawa sand. During the interval between 1915 and 1922 the development was confined to the gas sands found between 2,000 and 2,500 feet, but on July 14, 1922, George L. Miller No. 3 was completed as an oil well in the Layton sand, found at 2,752 feet. This well was deepened to the "Wilcox" sand in October, 1923, and had an initial production of 650 barrels.

STRATIGRAPHY

The rocks that are exposed in the Morrison field are of Permian age. They consist mostly of red shale and sandstone, but two limestones are

[1] Presented by title before the Association at the Tulsa meeting, March 26, 1927. Manuscript received by the editor, July 30, 1927. Reprinted from *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 10 (October, 1927), pp. 1087–95.

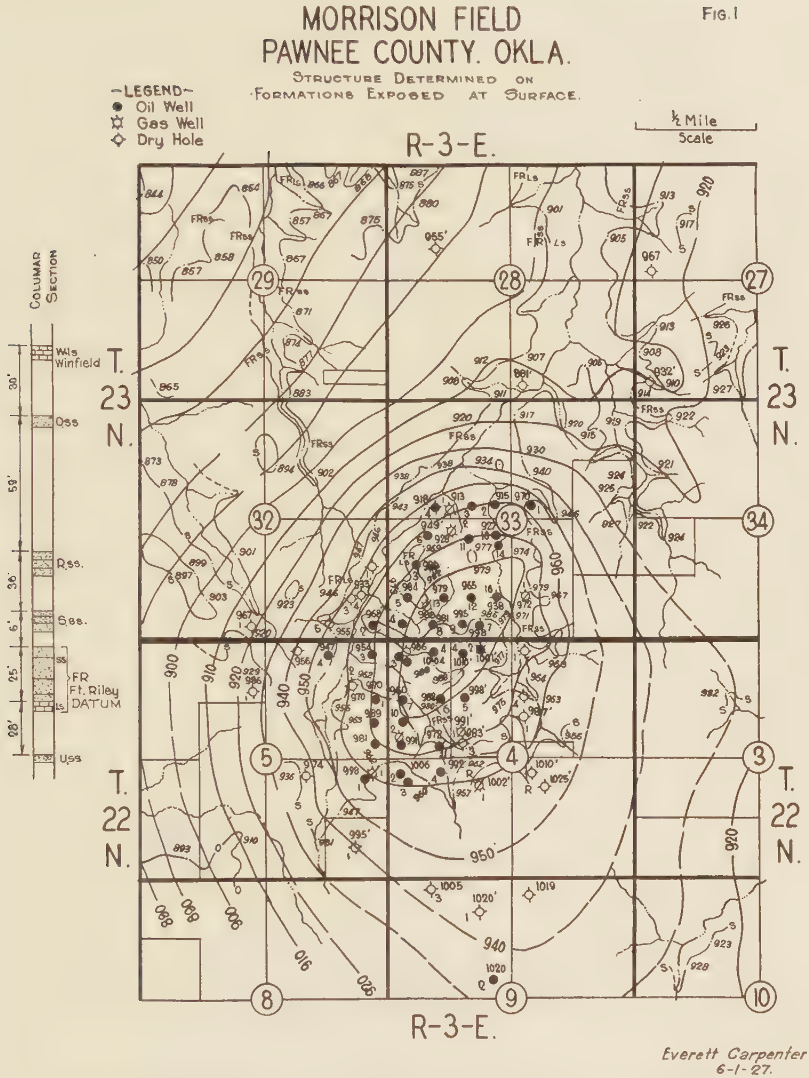


Fig. 1.—Geologic structure of the surface formations, Morrison field. Contours above sea-level. Contour interval, 10 feet.

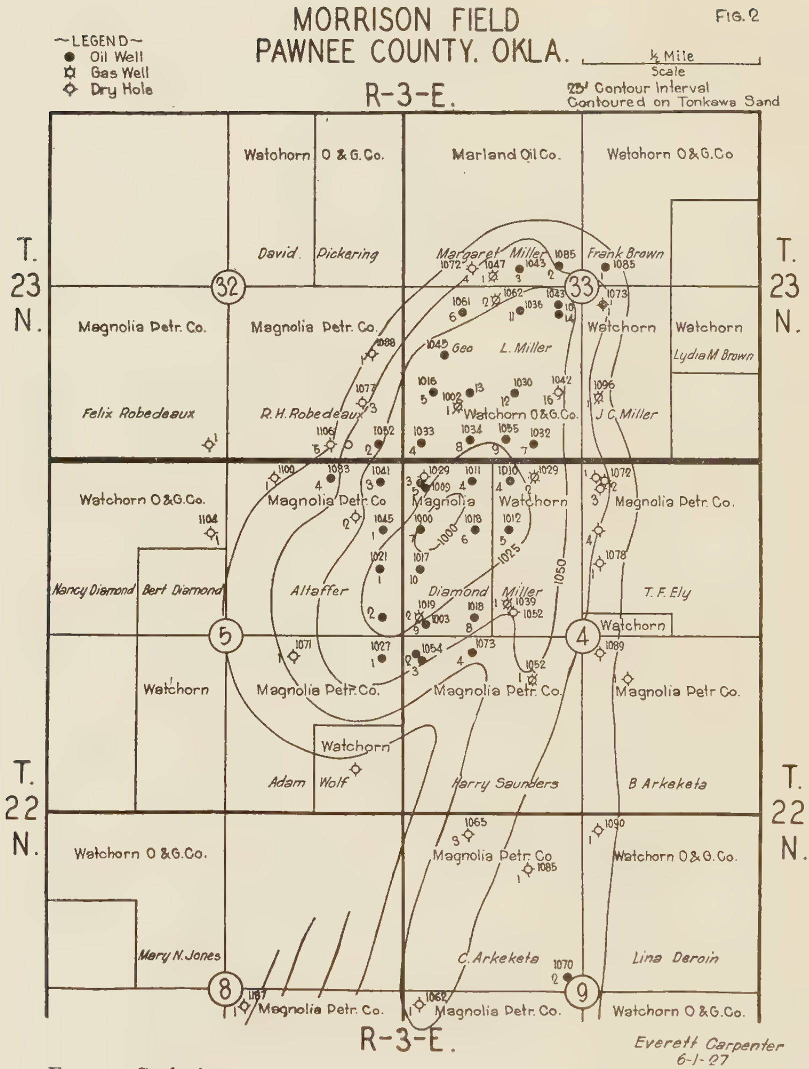


FIG. 2.—Geologic structure contoured on the Tonkawa sand in feet below sea-level, Morrison field.

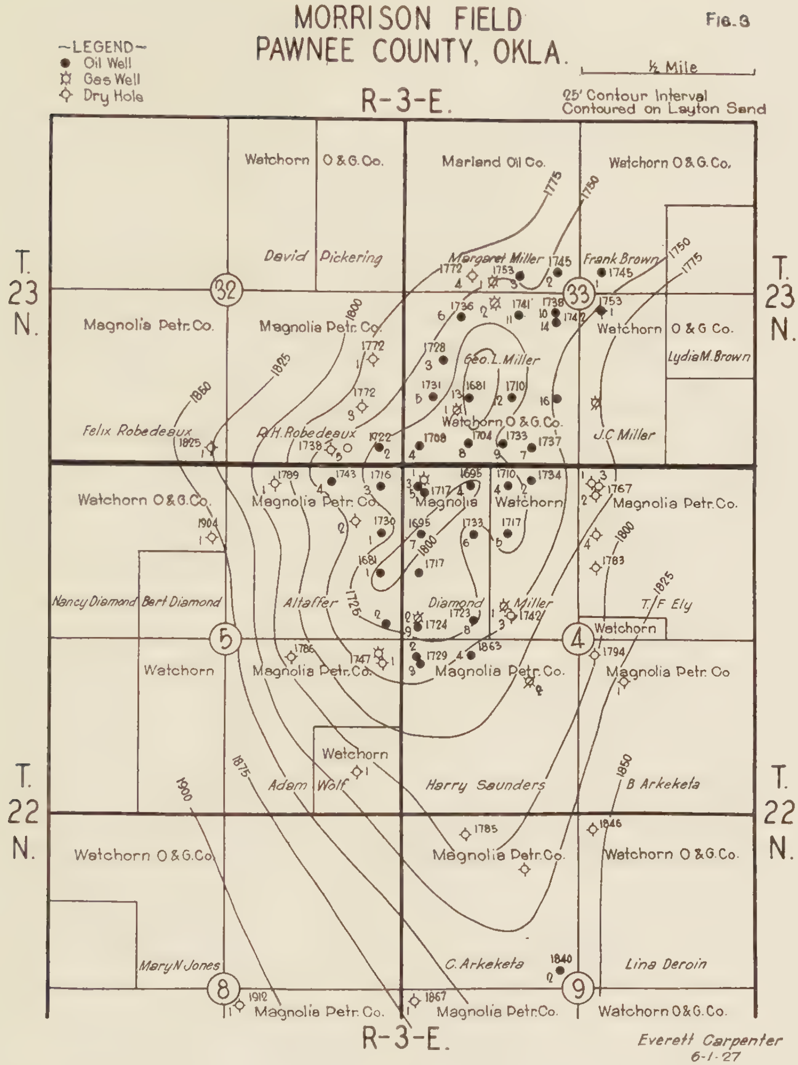


FIG. 3.—Geologic structure contoured on the Layton sand in feet below sea-level, Morrison field.

present. The Fort Riley limestone crops out in the field and is the datum used in mapping the structure. This formation has lost the calcareous nature it possesses in Kansas and northern Oklahoma, and consists mostly of sand, with a limestone bed about 10 feet thick at its base. The Winfield limestone crops out west of the field about 160 feet stratigraphically above the Fort Riley. The interval between the two consists of red sand and shale.

SUBSURFACE STRATIGRAPHY

Subsurface correlations in the Morrison field are comparatively difficult, due to the lack of persistent key beds. The Foraker limestone is found 500 feet below the Fort Riley, but it is not easily recognized. The first dependable correlation to be made is on the Tonkawa sand found at a depth of 2,000 feet. The section between the Tonkawa sand and the Layton sand, found at 2,700 feet, is irregular, and no accurate correlation is possible throughout wide areas. The Layton sand can be correlated in most of the area, and also the Kansas City–Oswego group. The "Mississippi lime" found on the structure at a depth of 3,800 feet below the Fort Riley is everywhere distinguishable; but on account of its variable thickness the depth of the "Wilcox" cannot be definitely forecast.

STRUCTURE

The structure as revealed by the surface rocks is a typical anticline (Fig. 1). It has a north-south length of about one mile and a productive width of about ½ mile. The fold is characterized by a reverse dip of about 40 feet, although probably not all of the east flank is exposed. The south end of the structure is not clearly revealed, due to the lack of exposures of any key horizons.

Several horizons may be used for subsurface mapping with essentially similar results. For the purpose of this study four horizons were used, namely, Tonkawa, Layton, "Mississippi lime," and "Wilcox" sand (Figs. 2, 3, 4, and 5). These formations, except the "Mississippi lime," contain oil or gas, and measurements to them are probably more accurate than others. The structure as revealed by subsurface rocks is similar in outline to that determined by surface exposures. In general the amount of closure increases with depth to the top of the "Wilcox" sand, where there is a closure of about 150 feet.

PRODUCTION

The production obtained from the Pennsylvanian strata is mostly gas, although oil has been found in commercial quantities in the Layton sand in several wells at a depth of about 2,700 feet. The producing sands are

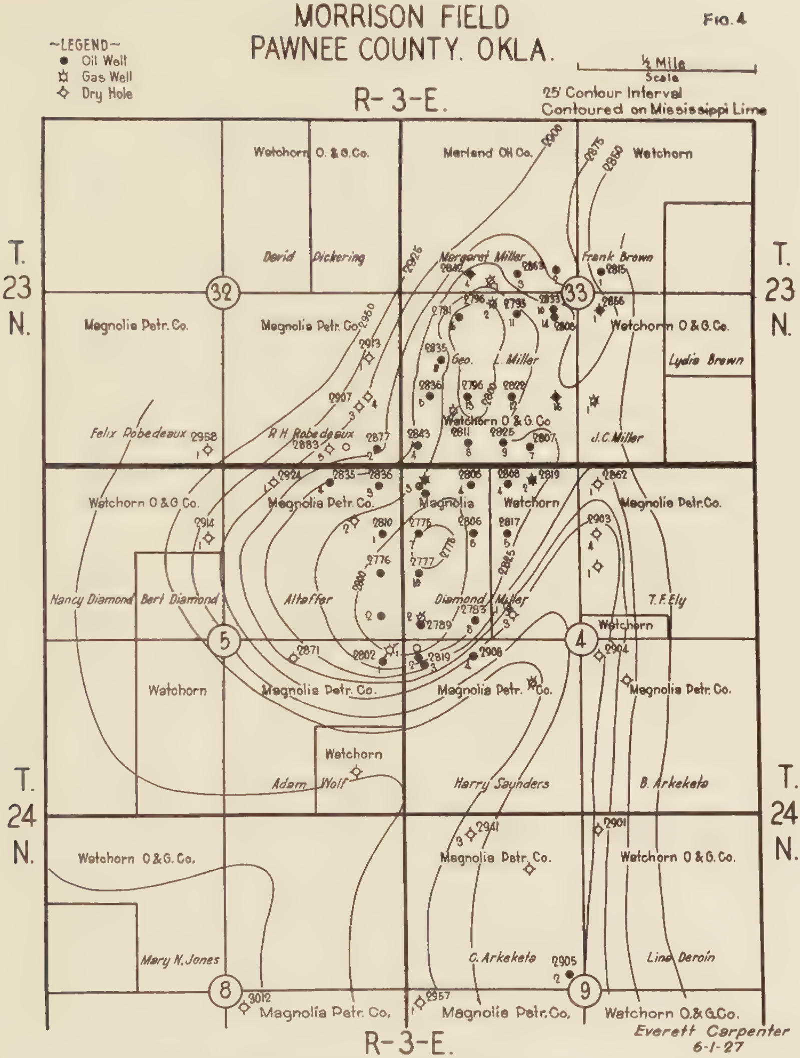


FIG. 4.—Geologic structure contoured on the "Mississippi lime" in feet below sea-level, Morrison field.

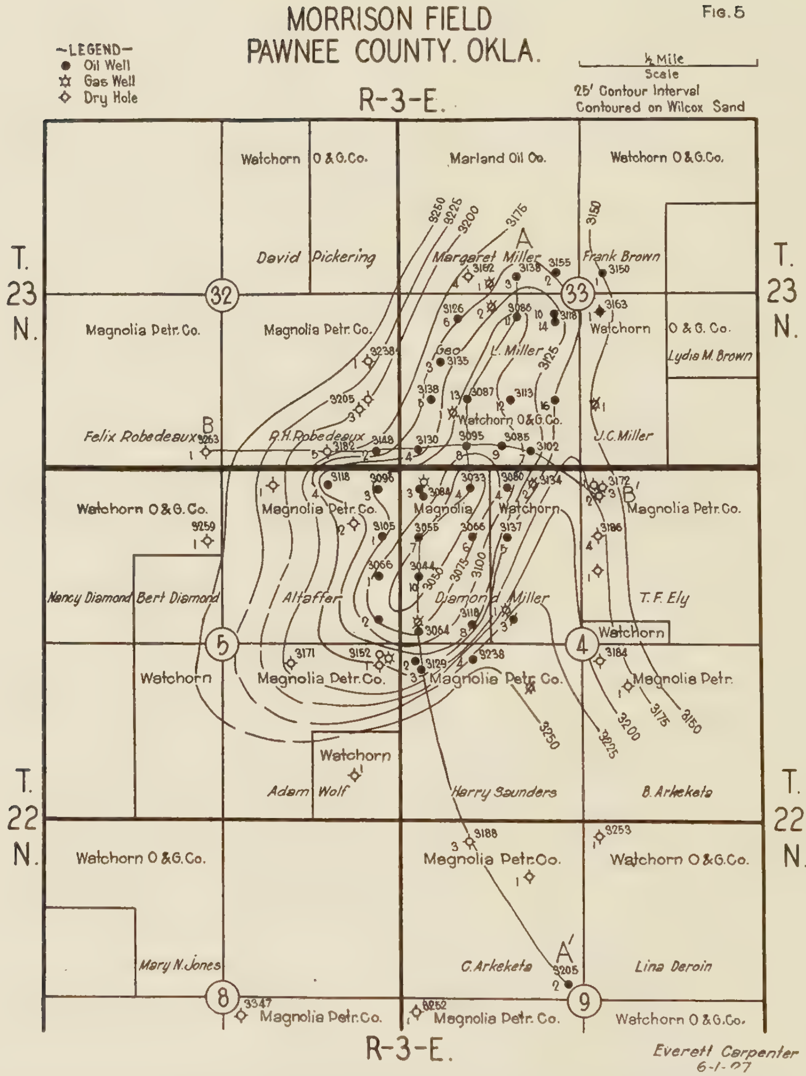


FIG. 5.—Geologic structure contoured on the "Wilcox" sand in feet below sea-level, Morrison field. Shows location of cross sections AA' and BB' (Figs. 6 and 7).

Fig. 6.—Geologic cross section *AA'* as shown by well logs. For location in field, see Figure 5. Depth shown in feet.

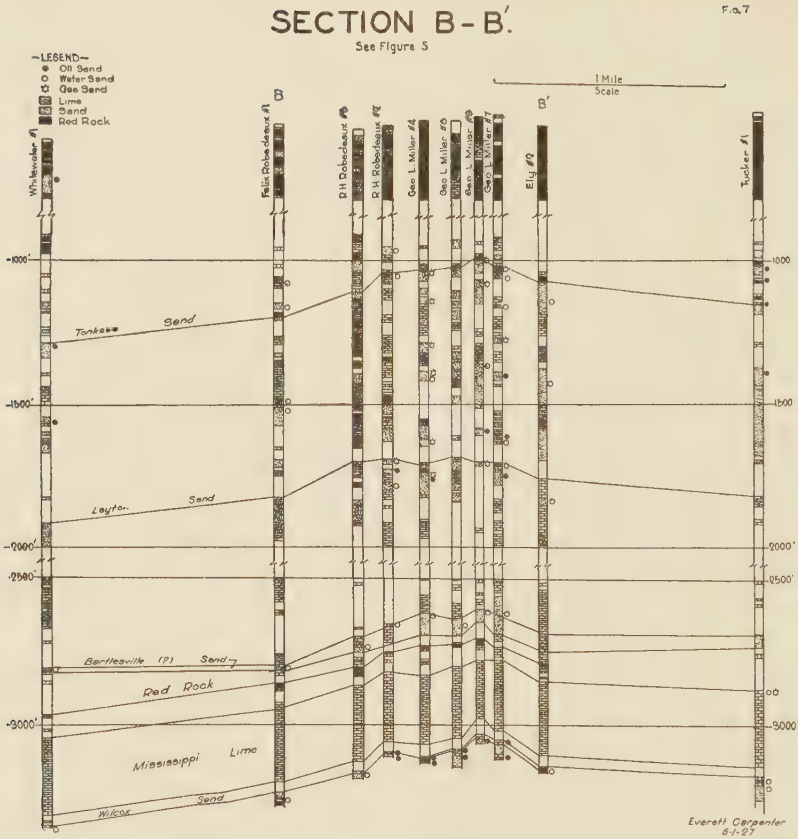


FIG. 7.—Geologic cross section *BB′* as shown by well logs. For location in field, see Figure 5. Depths shown in feet.

the Tonkawa gas sand at 2,000 feet, two unnamed gas sands at about 2,300 and 2,500 feet, and the Layton oil sand at 2,700 feet. The Bartlesville sand is probably present on the Morrison anticline, but it is unproductive. Some slight showings were obtained in the upper part of the "Mississippi lime," but they were not sufficient to be commercial.

The production obtained from the pre-Pennsylvanian strata is all from the "Wilcox." It is the best oil-producing formation, and has furnished more than 90 per cent of the oil in the field. It seems that all the oil-bearing horizons have been tested, but several showings in the siliceous lime have been reported in wells drilled off the structure. It is possible that when a deeper well is completed on the top of the dome, additional production may be obtained.

The following production data are from the office of the Corporation Commission and are believed to be accurate:

PRODUCTION OF THE MORRISON FIELD

Year	Barrels
1922	42,318
1923	97,576
1924	1,253,080
1925	2,232,996
1926	940,830
Total	4,566,800

At the close of 1926, the average yield for the field was more than 11,000 barrels per acre. The production during the remainder of the life of the field should be almost 15,000 barrels per acre.

RELATION BETWEEN STRUCTURE AND PRODUCTION IN THE MERVINE, PONCA, BLACKWELL, AND SOUTH BLACKWELL OIL FIELDS, KAY COUNTY, OKLAHOMA[1]

STUART K. CLARK[2] AND JAMES I. DANIELS[2]
Ponca City, Oklahoma

ABSTRACT

The four fields under discussion are located in Kay County, Oklahoma. Certain general statements are applicable to all these fields: (1) the folds are all of the familiar "granite-ridge" type; (2) due to the absence of notable unconformities above the base of the Pennsylvanian, structure maps of the several key horizons within the Pennsylvanian and Permian are similar in the mathematical sense of the term; and (3) the production in all of these fields is associated with well-defined anticlines or domes.

In the detailed discussion, therefore, the principal emphasis is placed on the seeming anomalies, that is, those structures which are not ideal examples of anticlinal production.

INTRODUCTION

The four fields which furnish the subject for discussion in this paper are all located in Kay County, north-central Oklahoma. Their exact locations are shown on the accompanying index map (Fig. 1).

The primary purpose of the writers is to present, as concisely as possible, the ascertainable facts in regard to the relation between structure and production in these fields. These facts are presented in graphic form by a series of structure maps on which the productive areas in the several producing horizons are indicated by shading, supplemented by two cross sections.

However, since some knowledge of the stratigraphy and geologic history of the area as a whole is essential to a thorough understanding of the structural conditions, and since there are some general statements regarding structure and the productive areas which are applicable to all of these fields, these topics will be summarized briefly before entering upon the discusssion of the individual fields.

STRATIGRAPHY

As the stratigraphy of Kay County has been discussed in detail in a recent publication of the Oklahoma Geological Survey,[3] no discussion of the formations is offered here.

[1] Read before the Association at the Tulsa meeting, March 24, 1927. Manuscript received by the editor, August 7, 1927.

[2] Marland Oil Company.

[3] Clark and Cooper, "Oil and Gas in Kay, Noble, Garfield, and Grant Counties," *Oklahoma Geol. Survey Bull. 40-H.*

The geologic sections encountered in each of the fields and their correlations are shown by the type logs in Figure 2.

GEOLOGIC HISTORY

The history of north-central Oklahoma, from Cambrian to Permian time, inclusive, falls into five major divisions.

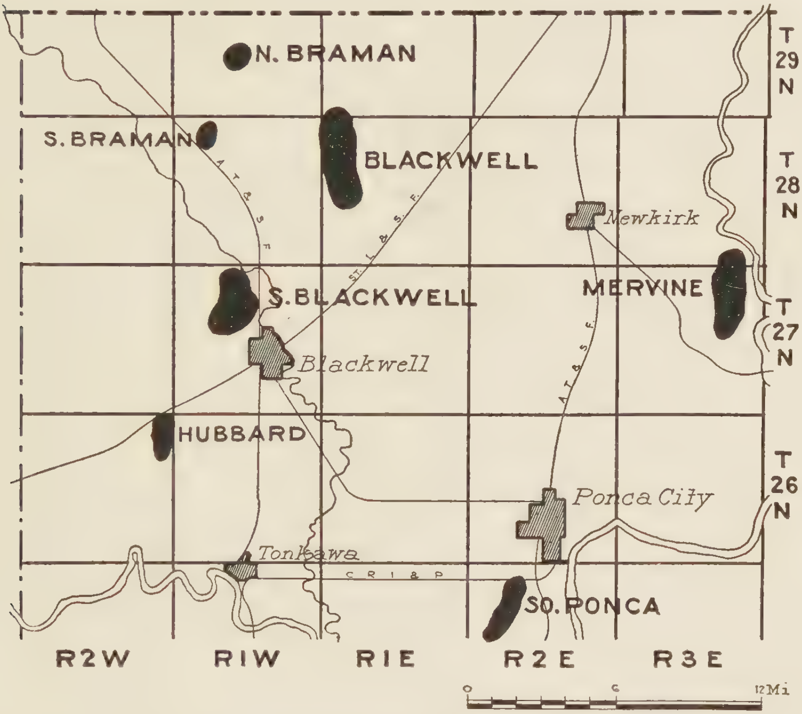


FIG. 1.—Index map showing the location of Mervine, Ponca, Blackwell, and South Blackwell oil fields, Kay County, Oklahoma.

1. A period of deposition extending from the Cambrian presumably until the close of Hunton time, although no Hunton or Sylvan are now present within the area under discussion.

2. A period of emergence during which the strata were tilted in a south-southwest direction and cut down by the forces of erosion to a peneplain in which all the formations from Arbuckle to Hunton were exposed in broad belts extending in a west-northwest direction.

The areal geology at the close of this period has been very accurately

mapped by Luther H. White.[1] Reference to his map shows three of these fields, Ponca and the two Blackwell fields, to be within the belt of exposure of the "Wilcox" sand.

It follows, therefore, that the first formation encountered below the Chattanooga shale in wells drilled in these fields should be the "Wilcox" sand. This is actually the situation.

The other field, Mervine, lies within the pre-Chattanooga outcrop area of the Tyner formation. In this field, however, there is evidence of a local fold prior to the close of this erosion period, since wells located on and near the crest of the present anticline, instead of encountering a normal thickness of Tyner and Burgen, either pass directly from "Mississippi lime" into the Arbuckle ("Siliceous lime") or at the most encounter a few feet of green shale and sand between these formations.

3. A period of deposition, during which the Chattanooga shale and "Mississippi lime" were laid down.

4. A period of emergence, during which the principal structure-forming movements affecting this area occurred. Extensive folding and faulting took place and erosion attacked the topographic "highs" thus created, reducing the height of some by several hundred feet. But as the erosion period was not sufficiently prolonged to bring about a peneplanation of the area, the topography was still rather rugged at the beginning of Pennsylvanian time, many of the hills exceeding 500 feet in height.

5. A period of deposition without notable interruption, during which the Pennyslvanian and Permain sediments were laid down. During the deposition of the earliest Pennsylvanian beds the tops of the pre-Pennsylvanian hills formed islands in the Cherokee sea. But at the close of Cherokee time they had all been submerged and covered with a blanket of shale, as is evidenced by the fact that the Oswego lime passes without interruption over the highest of them, although the thickness of the intervening shale is in some places no more than 50 feet. While this area was not wholly undisturbed by diastrophic movements during the entire Pennsylvanian-Permain period, it is obvious from the evidence available that such movements were relatively slight as compared with those which occurred at the close of Mississippian time. In fact, so far as the fields under consideration are concerned, their entire subsequent history appears to have been remarkably free from such disturbances, with the ex-

[1] "Subsurface Distribution of Pre-Chattanooga Rocks," *Oil and Gas Journal*, April 1, 1926. "Subsurface Distribution and Correlation of the Pre-Chattanooga ('Wilcox' Sand) Series of Northeastern Oklahoma," *Oklahoma Geol. Survey Bull. 40-B*, June, 1926.

ception of some faulting of late Permian or post-Permian age. The anticlines in the post-Mississippian rocks evidently are simply modified impressions of the resistant pre-Pennsylvanian hills underlying them. The degree of modification naturally varies in direct proportion to the thickness of intervening strata.

STRUCTURE AND ITS RELATION TO PRODUCTION

Three general statements regarding structure and its relation to production can be made.

1. The folds involved are all of the familiar granite-ridge type.

2. Due to the absence of any notable unconformities above the base of the Pennsylvanian, a structure map of any area, contoured on any key bed within the Pennsylvanian or Permian, is similar, in the mathematical sense of the term, to a structure map of the same area contoured on any other key bed within the Pennsylvanian or Permian. That is, the essential structural features are identical, practically the only difference being in the degrees of dip indicated.

Advantage has been taken of this fact in the preparation of the accompanying illustrations, using only one post-Mississippian structure map as a base on which to show the producing areas in the several shallow productive horizons. The horizon selected for each field was that one which could be mapped with the greatest accuracy.

3. The production in all of these fields is associated with well-defined anticlines or domes.

The principal interest therefore attaches to production not found in the ideal relation, that is, confined to the crest of the anticline.

In the following discussion of the relation of structure to production the principal emphasis will be placed upon these apparent anomalies and their causes.

In the fields included in this report there are some horizons which produce oil or gas in only a few wells. These are purposely omitted from the detailed discussion.

The following is a list, by fields, of the omitted horizons:

Mervine field	(1) 1,200-foot oil sand (2) 1,500-foot oil sand (3) 1,800-foot oil sand
Ponca field	(1) 950-foot oil sand (2) 1,300-foot oil sand
Blackwell field	(1) 1,400-foot gas sand

MERVINE FIELD

Newkirk sand.—Figure 3 shows the productive area in the Newkirk or 1,000-foot sand of the Mervine field outlined on the structure map of the same horizon. This represents an ideal example of anticlinal accumulation.

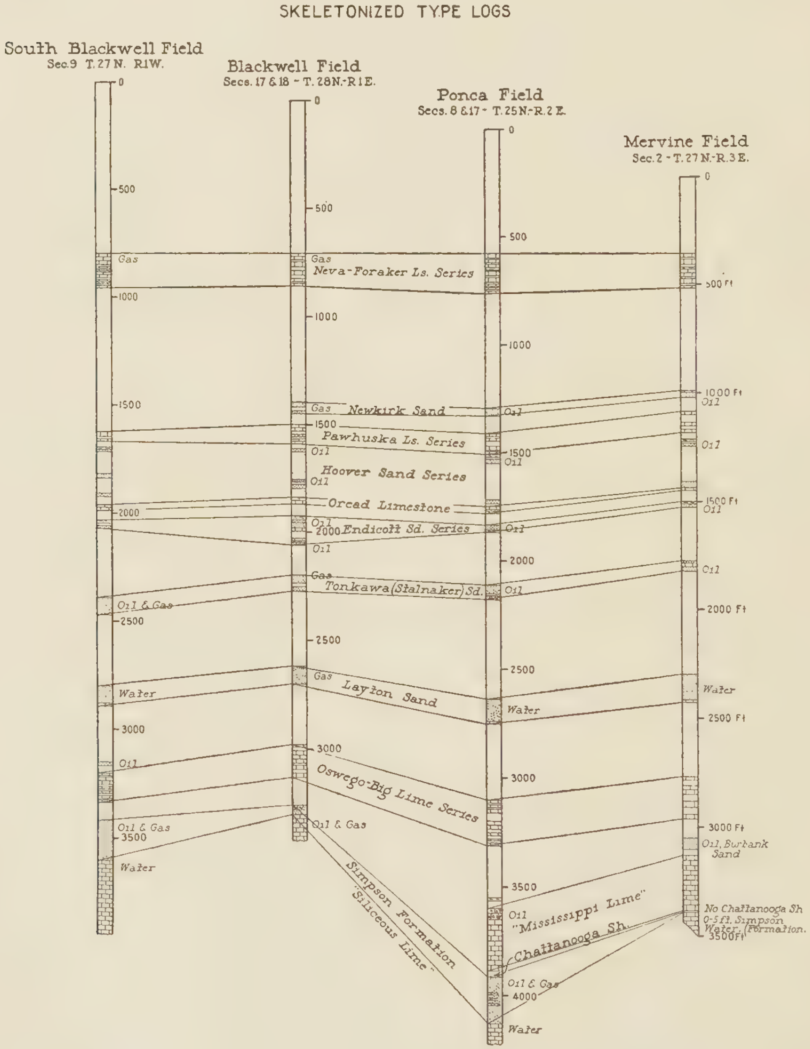


FIG. 2.—Type logs showing correlation of geologic sections in Mervine, Ponca, Blackwell, and South Blackwell fields.

Burbank sand.—The productive area in the Burbank sand is shown in Figure 4 on a map contoured on the top of the "Mississippi lime," since the topography of the pre-Pennsylvanian hill of "Mississippi lime"

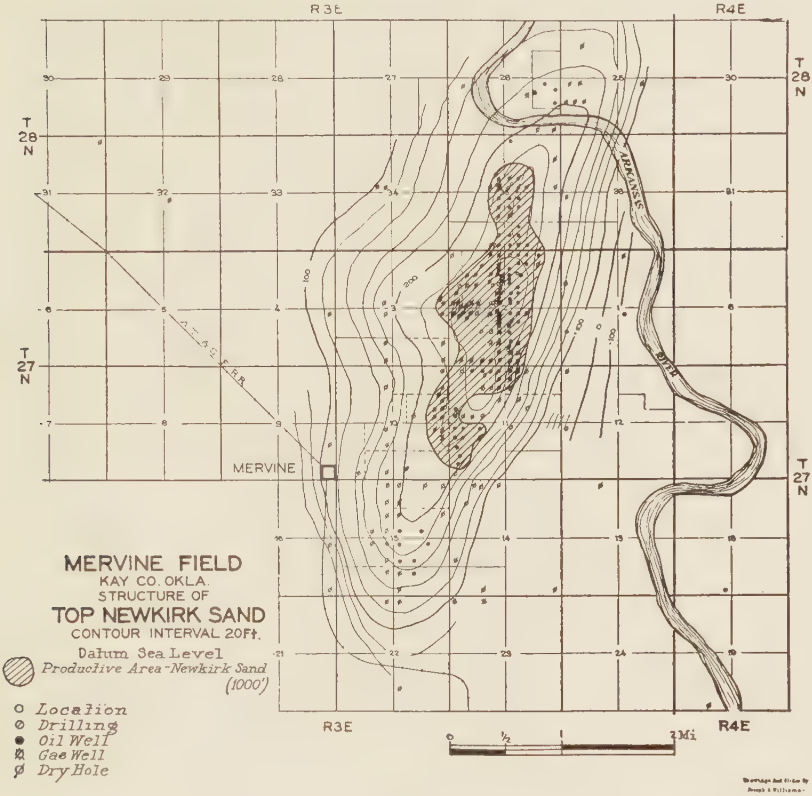


FIG. 3

was probably the controlling factor in the deposition of this local sand body on the south end of the anticline.

PONCA CITY FIELD

Ponca sand.—The productive area in the Ponca or 1,500-foot sand is shown in Figure 5 on a structure map of the 1,300-foot sand. With the exception of a barren area in the NE. ¼ of Section 8, this furnishes another nearly ideal example of anticlinal accumulation.

1,800-foot sand.—Figure 5 also shows the productive area of the 1,800-foot sand. This sand is of local occurrence, being replaced laterally by red shales, thus accounting for the restricted producing area.

Tonkawa sand.—Figure 5 also shows the productive areas in the Tonkawa, or 2,100-foot sand. Field observations during the drilling of this horizon indicate that the sporadic distribution of these productive areas is due to the irregular nature of the upper part of this sand body.

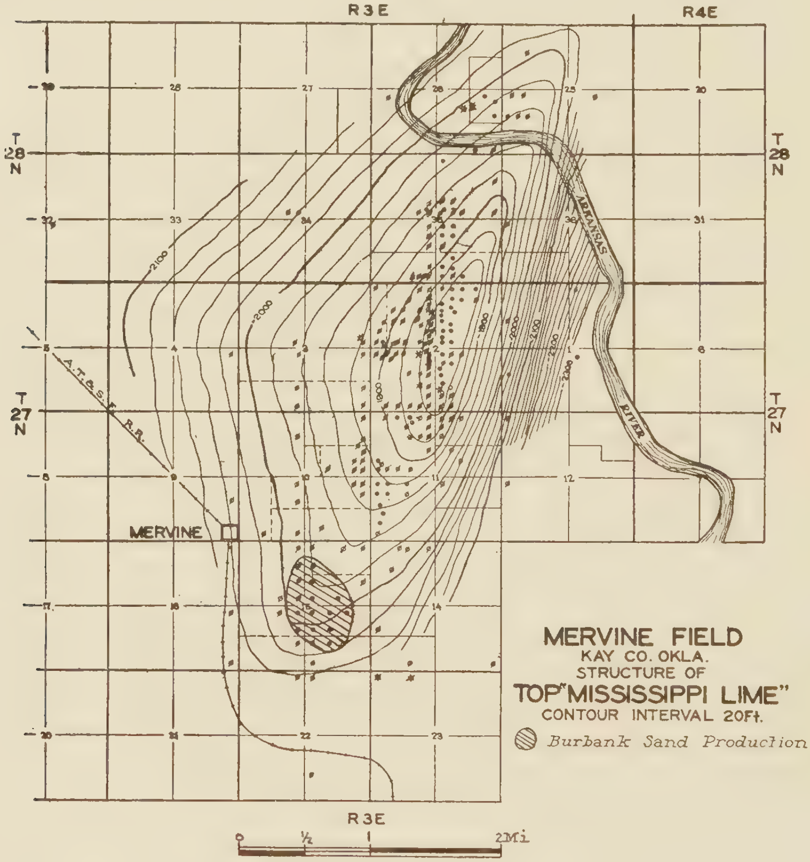


FIG. 4

"Mississippi lime" and "Wilcox" sand production.—For the sake of contrast the productive areas in the top of the "Mississippi lime" and the "Wilcox" sand are both shown on a map contoured on the former horizon (Fig. 6).

It will be noticed that the "Wilcox" production is confined to the higher portions of the anticline, whereas the "Mississippi lime" produc-

tion occurs on its flanks at the southern or plunging extremity. This latter situation is explained by the fact that the "Mississippi lime" oil occurs in a bed of porous altered chert, presumably a residual product resulting from the concentration of the silica of that part of the "Mississippi

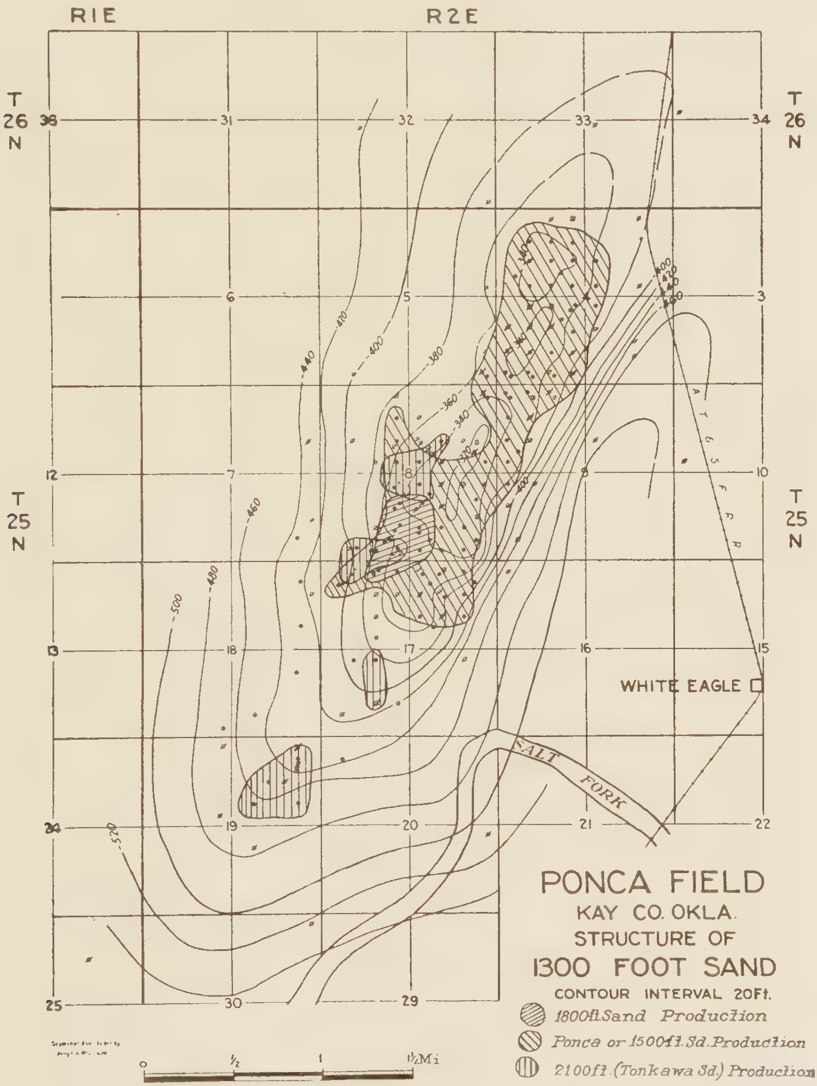


FIG. 5

lime" which was removed by erosion during the period of emergence just preceding the Pennsylvanian. As a natural consequence of its mode of

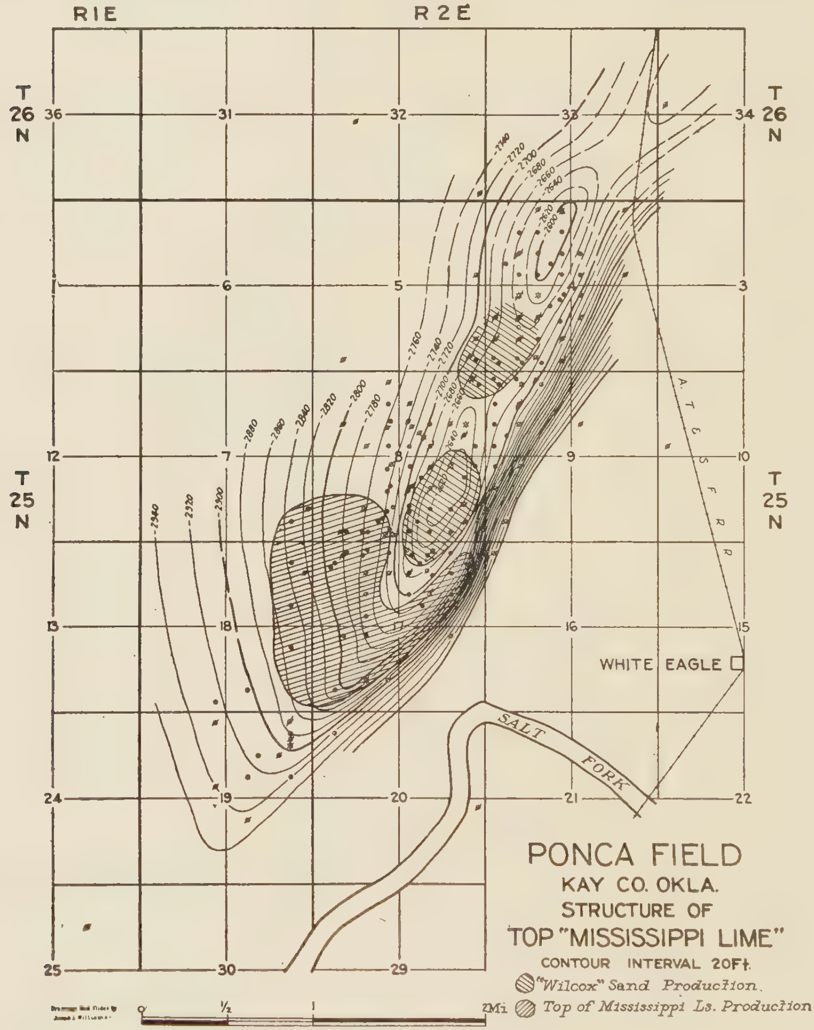


FIG. 6

origin, this accumulation of chert was concentrated on the flanks of the anticline around the southward-plunging extremity, the crest of the fold being left practically bare.

BLACKWELL FIELD

Neva lime gas production.—The shallowest production of consequence in the Blackwell field is the gas found in the Neva limestone at depths ranging from 700 to 750 feet. The extent of the productive area and its relation to the structure as mapped on the top of this limestone is shown in Figure 7.

It will be noticed that the producing area covers the top of the north dome, but that instead of conforming to the structure in the southern part of the field, it extends southwest in a belt about a mile and a half wide. This zone of gas production occupies a progressively lower position on the west flank of the major anticline as it extends southward.

Although it may be presumed that this phenomenon is probably the result of differences in the porosity of the limestone which forms the reservoir rock, in the absence of detailed information based on actual cuttings from this horizon throughout the area, positive conclusions as to the cause of this situation are wholly unwarranted.

Upper and lower Hoover sands.—Figure 7 indicates the extent of the productive areas in the upper and lower Hoover sands.

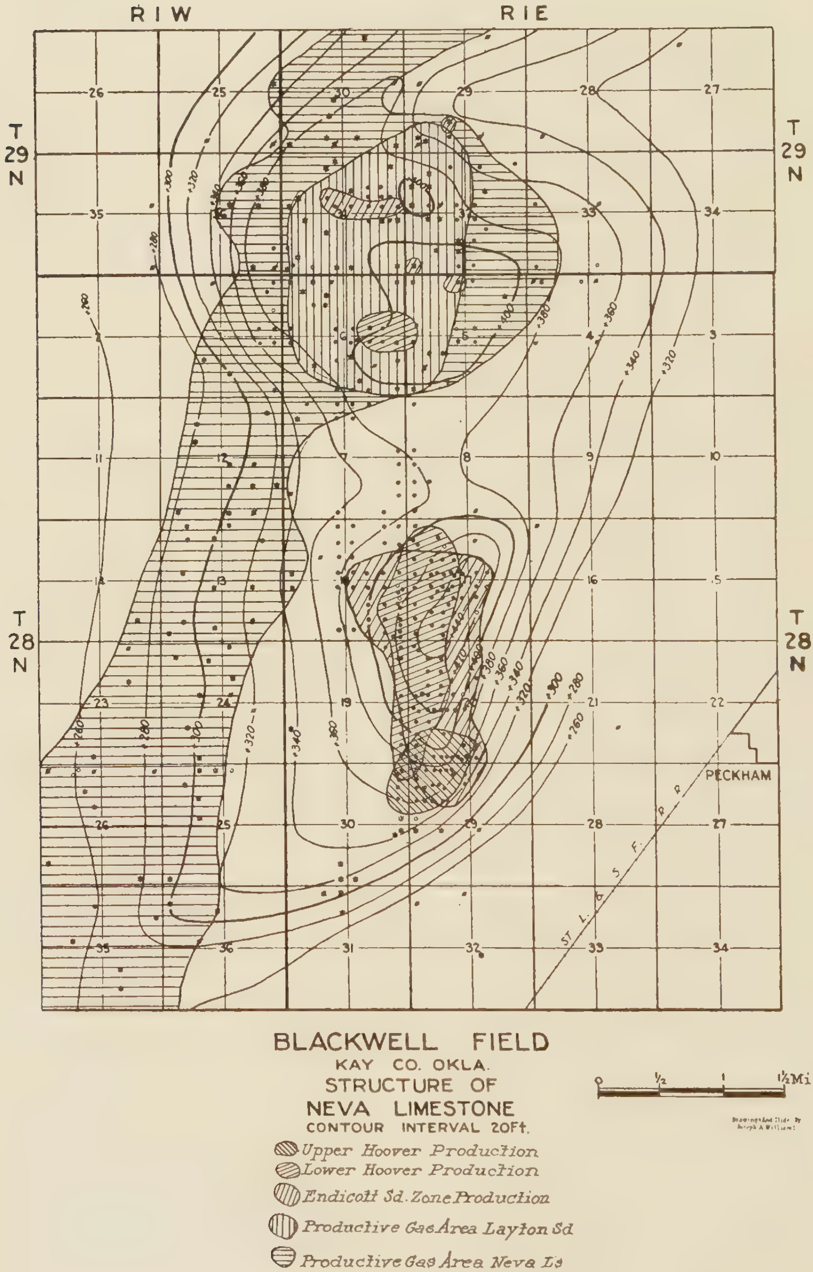
The lower Hoover sand is persistent over the entire anticline. Production from it is confined largely to the upper part of the structurally higher and more sharply folded south dome, although a few wells on the crest of the north dome also produce from this sand.

Production from the upper Hoover sand is limited to an area of about 200 acres on the southern extremity of the south dome. This is seemingly due to the lenticular character of the sand body, as its stratigraphic position is occupied by red rock over most of the area of the field.

Endicott sand zone.—The productive areas of the two sands in this zone are practically co-extensive. Their major producing area occurs on the south dome and is approximately conformable to its structure, shown in Figure 7. Sporadic occurrences of oil in this horizon are also found on the north dome.

Layton sand.—The Layton sand produces gas only, throughout an extensive area on the north dome, but is water-bearing over the higher south dome (Fig. 7).

"Wilcox" sand and "Siliceous lime."—Figure 8 shows the extent of the "Wilcox" sand and "Siliceous lime" producing areas and their relation to the structure as contoured on the top of the Ordovician. The "Wilcox" sand production extends over the entire top of the north dome, but is confined to the north and west flanks of the south dome. The "Siliceous lime" produces only on the crest of the south dome.



R I W
R I E
T 29 N
T 28 N
PECKHAM
ST. L. & S. F. R. R.
BLACKWELL FIELD
KAY CO. OKLA.
STRUCTURE OF
NEVA LIMESTONE
CONTOUR INTERVAL 20Ft.
Upper Hoover Production
Lower Hoover Production
Endicott Sd. Zone Production
Productive Gas Area Layton Sd
Productive Gas Area Neva Ls
0 ½ 1 1½ Mi

FIG. 7

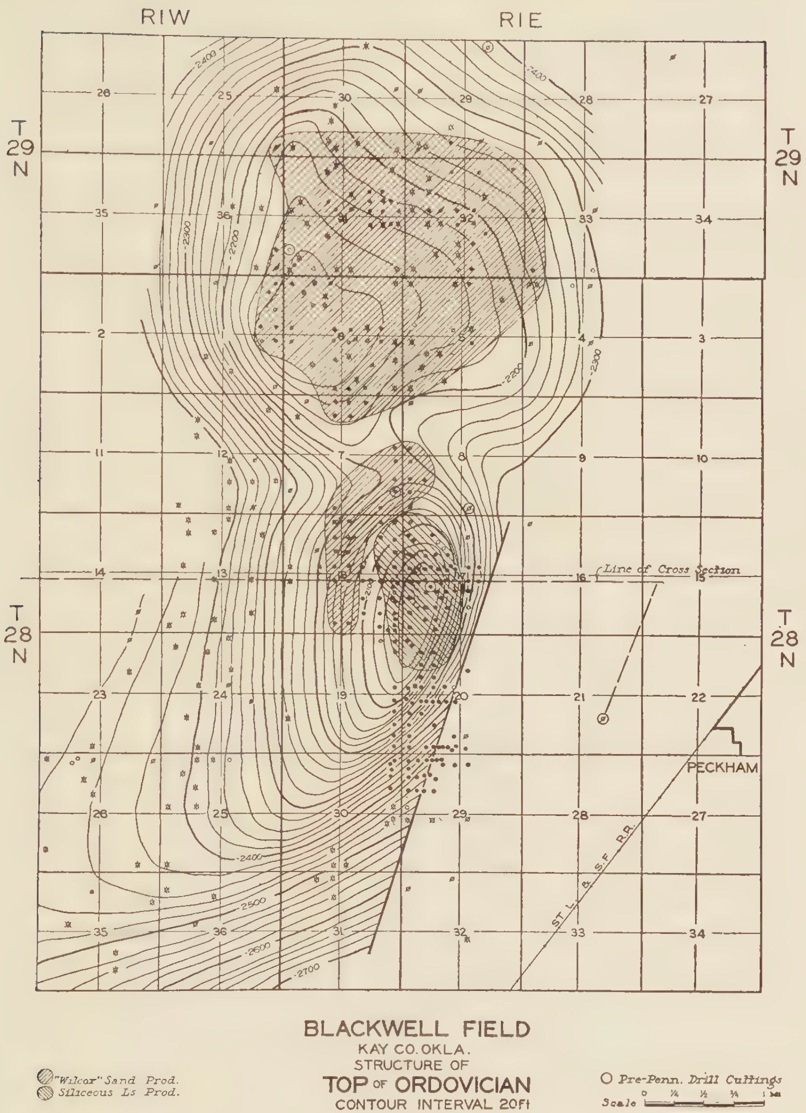


FIG. 8

The explanation for the latter situation is indicated in the east-west cross section through the south dome. Figure 9 shows that on the crest of this fold the entire thickness of "Mississippi lime," Chattanooga shale,

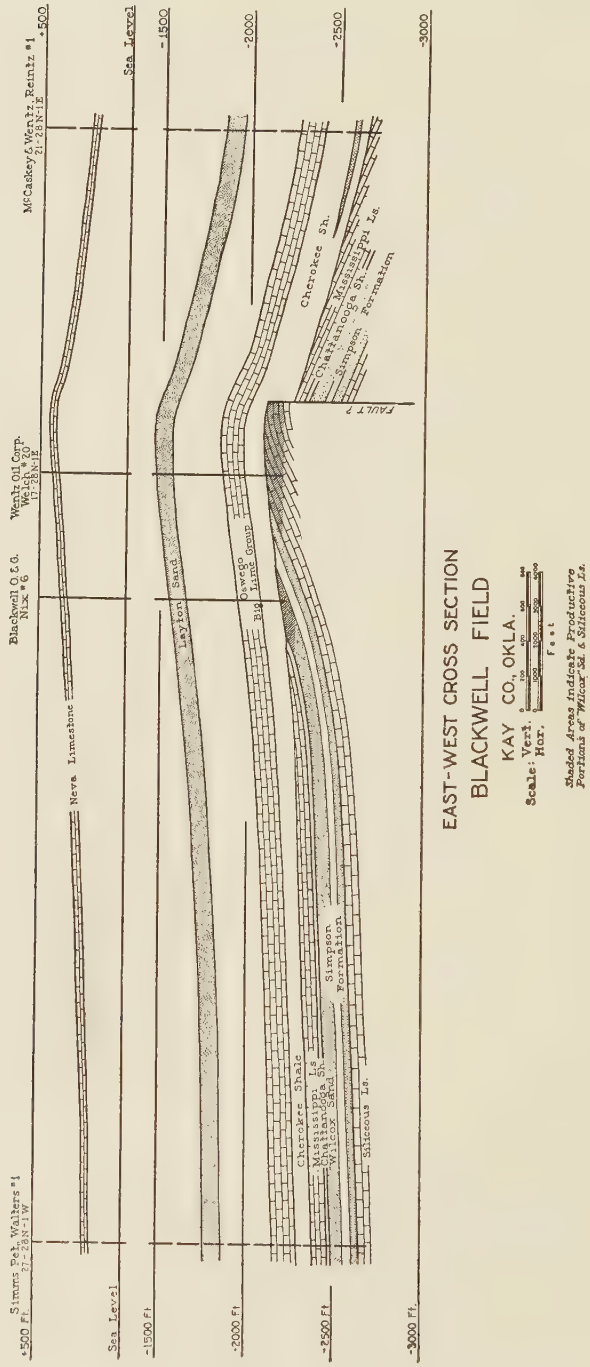

EAST-WEST CROSS SECTION
BLACKWELL FIELD
KAY CO., OKLA.
Scale: Vert.
Hor.
Feet
Shaded Areas indicate Productive Portions of "Wilcox" Sd. & Siliceous Ls.
McCaskey & Wentz, Reintz #1
21-28N-1E
Wentz Oil Corp.
Welch #20
17-28N-1E
Blackwell O. & G.
Nix #6
Simms Pet. Walters #1
27-28N-1W
+500 Ft.
Sea Level
-1500 Ft.
-2000 Ft.
-2500 Ft.
-3000 Ft.
+500
Sea Level
-1500
-2000
-2500
-3000
Neva Limestone
Layton Sand
Oswego
Big Lime Group
Cherokee Sh.
Mississippi Ls.
Chattanooga Sh.
Simpson Formation
FAULT ?
Cherokee Shale
Mississippi Ls.
Chattanooga Sh.
Wilcox Sand
Siliceous Ls.

FIG. 9

and the Simpson formation, which includes the "Wilcox" sand, had been removed by erosion prior to the deposition of the Cherokee shale.

Since the evidence upon which this map and cross section are based is comparatively meager, it seems desirable to point out briefly just what evidence was available and how it was used, so that their limitations may be clearly understood.

Fortunately, drill cuttings were available, in the files of the Marland Oil Company and the Wentz Oil Corporation, which made it possible definitely to establish the pre-Pennsylvanian sections encountered and the identity of the productive horizons in several key wells in the field. These wells are all encircled on the structure map.

By a careful study of the drillers' logs of the other deep wells in the field it was possible to add to the precise data furnished by cuttings sufficient control to admit of making a fairly comprehensive map and cross-section.

An additional check as to the identity of the producing horizon in wells for which cuttings were not available was furnished by analyses of gas from these wells, since the "Wilcox" gas is a "sweet" gas, whereas the "Siliceous lime" gas is suphur-bearing.

SOUTH BLACKWELL FIELD

The structure of this field has some exceptional features which are worthy of comment. Although it lies along the Blackwell-Garber line of folding, in contrast to the ordinary anticline with its major axis merely a continuation of that line, the salient structural feature in this field is a broad, poorly developed dome, with its greatest dimension extending from northwest to southeast (Figs. 10, 11, and 12).

On the west this dome is cut off by a fault of Permian or post-Permian age. The fault is normal, its plane dipping about 45° W. (Fig. 12). It happens that there are no wells so located as to give a direct measurement of the amount of displacement at the Neva horizon. But in a well in the southwest corner of the NE. ¼ of Sec. 7, which was drilled through the fault plane somewhere in the shale interval between the Stalnaker and Layton sands, a vertical displacement of 125 feet was indicated by the reduced interval between those sands.

It seems evident that the forces which were responsible for this faulting operated to prevent the development of the common type of anticline by elevating a portion of what would normally be the west flank of that anticline to practically the same level as its crest.

Neva lime gas production.—Figure 10 shows the extent of the Neva

lime gas production in its relation to the structure of that same horizon. Although there is little apparent conformity between the structure contours and the boundaries of the gas area, this producing zone does tend to follow the alignment of the major line of folding.

Stalnaker and 3,100-foot sands.—The productive areas in the Stalnaker (Tonkawa) and the 3,100-foot sands are outlined in Figure 10. The Stal-

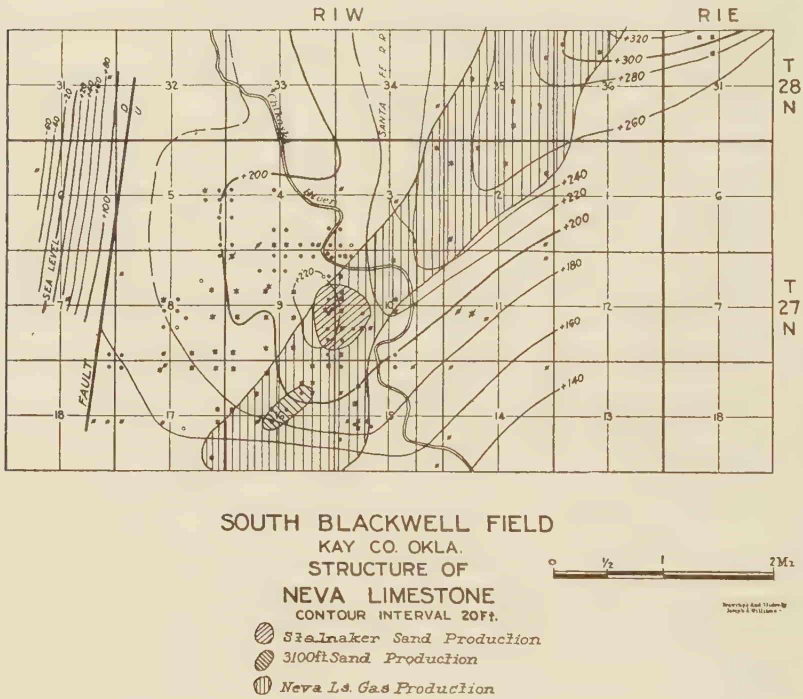


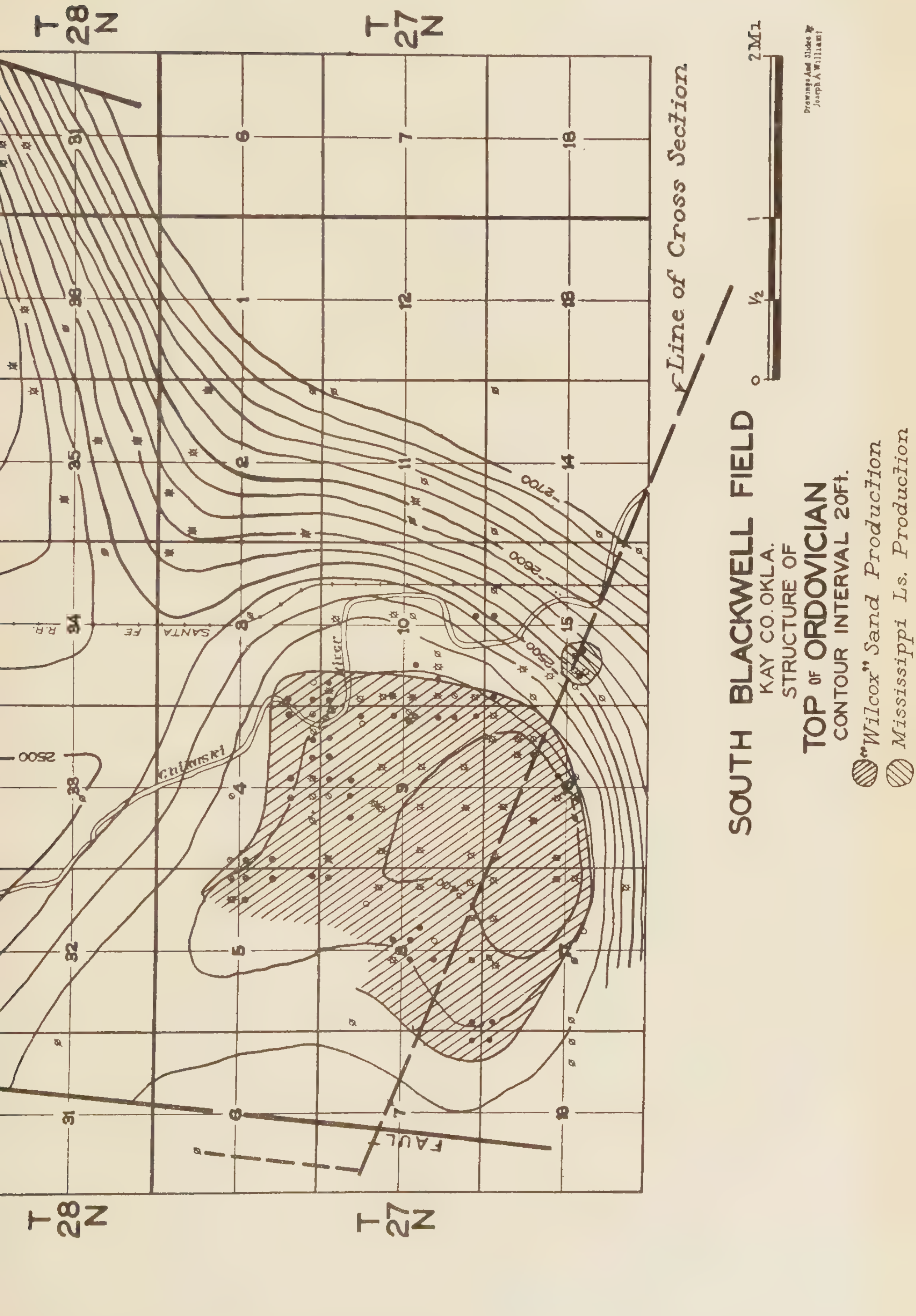
FIG. 10

naker sand produces throughout an area of about 160 acres, which practically coincides with the crest of the fold.

The 3,100-foot sand produces only in a small area in the center of Section 16.

Mississippi lime" and "Wilcox" sand.—Figure 11 shows the areas of "Mississippi lime" and "Wilcox" sand production in relation to the structure of the top of the Ordovician ("Wilcox" sand).

The "Mississippi lime" (chert) produces in only a very small area on the southeast flank of the fold. Over the crest the entire thickness of "Mississippi lime" is absent.


SOUTH BLACKWELL FIELD
KAY CO. OKLA.
STRUCTURE OF
TOP OF ORDOVICIAN
CONTOUR INTERVAL 20Ft.
"Wilcox" Sand Production
Mississippi Ls. Production
Line of Cross Section
T 28 N
T 27 N
FAULT
SANTA FE R.R.
Chikaskia
River
2700
2600
2500
0 1/2 1 2 Mi.

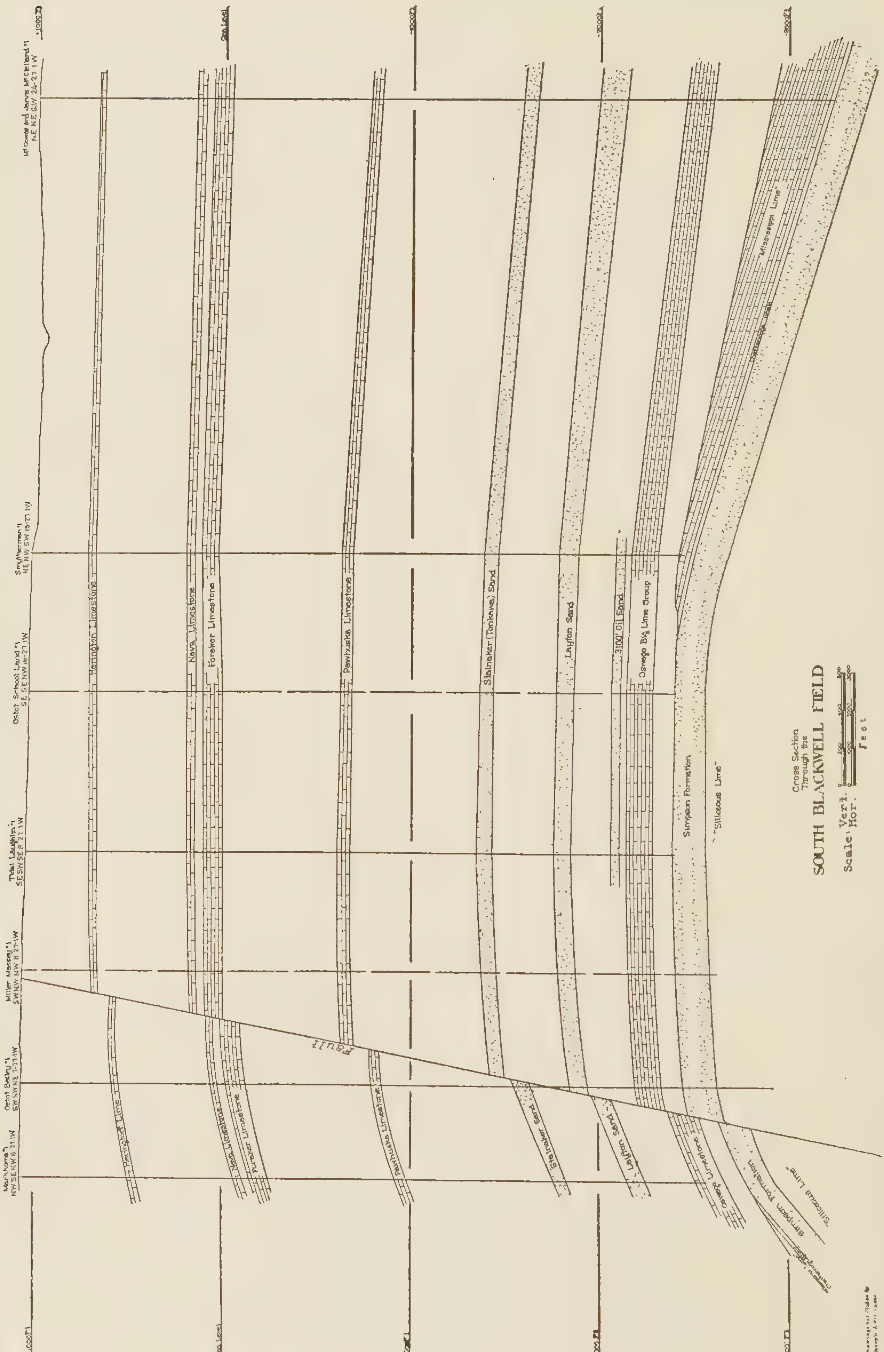

Cross Section Through the
SOUTH BLACKWELL FIELD
Scale, Vert. Hor.
Feet
Sea level
Herington Limestone
Neva Limestone
Foraker Limestone
Pawhuska Limestone
Stalnaker (Tonkawa) Sand
Layton Sand
3100' Oil Sand
Oswego Big Lime Group
Simpson Formation
"Siliceous Lime"
"Mississippi Lime"
Fault
Herington Lime
Stalnaker Sand
Layton Sand
Oswego Limestone
Simpson Formation
"Siliceous Lime"

FIG. 12

Although the "Wilcox" sand was exposed over the entire crest of the dome by the removal of the "Mississippi lime" and Chattanooga shale, the sand itself evidently suffered very little erosion, probably because of the broad flat expanse which it presented, due to the peculiar structure of the area.

The sand is productive over practically the entire crest of the dome. During the early stages of development the production was gas exclusively, but as development approached the later defined limits of the field a fringe of combined oil and gas wells was added around the margin of the gas field.

Figure 12 shows in cross section the relation of the "Mississippi lime" and "Wilcox" sand production to the structure of the field.

GARBER FIELD, GARFIELD COUNTY, OKLAHOMA[1]

WESLEY G. GISH[2] AND RAYMOND M. CARR[3]
Tulsa, Oklahoma

ABSTRACT

The Garber field, in T. 22 N., R. 3–4 W., Garfield County, Oklahoma, was discovered November 6, 1916, by the Exchange Oil Company's Hoy No. 1, in the northeast corner of Sec. 25, T. 22 N., R. 4 W., which had an initial production of 90 barrels of high-gravity oil from 1,138 to 1,150 feet in the Lower Permian. Eleven oil and gas sands were found in the subsequent shallow sand development. On April 6, 1925, the Sinclair Oil and Gas Company's Belveal 25, in the northeast corner of Sec. 24, T. 22 N., R 4 W., came in with an initial production of 2,600 barrels from the Ordovician limestone from 4,377 to 4,394 feet. This inaugurated another drilling campaign in which ten oil and gas horizons were exploited, and on March 19, 1927, the field had produced approximately 36,000,000 barrels from 23 horizons. The Permian and Pennsylvanian sediments exhibit very irregular lateral gradation in their shale, sandstone, and limestone phases, which condition greatly influenced petroleum accumulation. Portions of the Garber structure existed as a positive element or island from middle Tyner of Ordovician age until late Cherokee of Lower Pennyslvanian. Upthrusting of a continuous or oscillatory nature undoubtedly occurred in some minor degree throughout Pennsylvanian and early Permian time. A minimum of 1,000 feet of sediments is missing in the pre-Pennsylvanian unconformity, and the Pennsylvanian rocks show a minimum reduction of 700 feet from normal thickness. Criteria of tension fractures and fissures are present. Some conditions indicate possibility of vertical migration of oil and gas. The shallow oils are characterized by high gravity. Oil from the Ordovician rocks does not have the sulphur content characteristic of the "Siliceous lime" oil of the Tulsa-Osage district. The Ordovician oil accumulated in crystalline dolomite horizons.

INTRODUCTION

The Garber field is in T. 22 N., R. 3–4 W., Garfield County, Oklahoma, and is one of the major oil-producing areas in the Ponca City–Enid district of north-central Oklahoma. Exchange Oil Company's Hoy No. 1, northeast corner of Sec. 25, T. 22 N., R. 4 W., the discovery well, was drilled in, November 6, 1916, with an initial production of 90 barrels of high-gravity oil, from a depth of 1,138–1,150 feet in sand in the Lower Permian. The location for a test well to be drilled to a depth of 4,500 feet in the northeast corner of Section 25 was recommended in a geological report of March, 1916, by Dorsey Hager after a reconnaissance and detailed

[1] Read before the Association at the Tulsa meeting, March 25, 1927. Manuscript received by the editor, September 9, 1927. Published by permission of the Sinclair Oil and Gas Company.

[2] Chief geologist, Sinclair Oil and Gas Company.

[3] Petroleum engineer, Sinclair Oil and Gas Company.

field examination by Hager, Ben Belt, and Huntsman Haworth. Twelve oil and gas sands at depths less than 2,300 feet were developed in the subsequent drilling campaign which yielded 16,800,000 barrels of oil.

On April 6, 1925, the Sinclair Oil and Gas Company's Belveal No. 25, in the northeast corner of Sec. 24, T. 22 N., R. 4 W., came in with an initial production of 2,600 barrels at a depth of 4,377–4,394 feet in the Ordovician sediments. Eight additional oil horizons were discovered in the following development, which was unique in that the prolific Ordovician limestone was drilled first and the other horizons subsequently tested on the basis of rotary cores, samples, and formation records obtained in the deep-sand campaign. The combined shallow- and deep-sand production from April, 1925, to March, 1927, was 20,000,000 barrels. The approximate gross recovery of the field from 1916 to 1927, inclusive, is 36,800,000 barrels. Sinclair Oil and Gas Company's Hartley No. 19, in the southwest corner of the NW. $\frac{1}{2}$, Sec. 18, T. 22 N., R. 3 W., had an initial production of 18,181 barrels, and Hartley No. 27, in the northwest corner of the same lease, produced 25,000 barrels the first twenty-four hours, which is the largest initial production of any well drilled in the state of Oklahoma.

On March 15, 1927, the gross production for the field was 17,876 barrels from 798 wells. Only proved locations and others necessitated by drilling requirements are being drilled at this time.

STRATIGRAPHY

The Garber member of the Enid group is typically exposed in the southern part of the field.

The Garber formation includes a series of red clay shales, red sandy shales, and red sandstones lying above the Wellington. The name is from the town of Garber, in eastern Garfield County, Oklahoma, where the formation is well exposed.[1]
The Garber formation has a lower shaly phase, which is sometimes spoken of as the "lower Garber," and an upper sandy phase, which is known as the "upper Garber."

The Hennessy is throughout a clay-shale formation, and as such is easy to differentiate from the sub- and superjacent formations, which consist chiefly of sandstone. Its lower limit is the heavy sandstone at the top of the Garber, and its upper limit the base of the Duncan sandstone. The shales of the Hennessey differ from other red shales in the lower part of the Enid group in that they are rarely fissile or laminated, but are more commonly blocky and break with a conchoidal fracture, having the appearance of "joint clay." The Hen-

[1] F. L. Aurin, H. G. Officer, and Charles N. Gould, "The Subdivision of the Enid Formation," *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), p. 794.

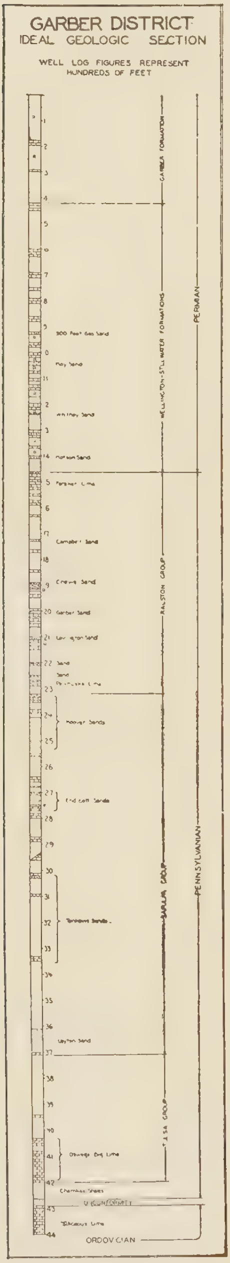


FIG. 1.—Ideal geologic section, Garber district, Oklahoma.

nessey as a whole is also characterized by numerous bands or streaks, white or light green in color, varying in thickness from a few inches to 4 feet or more.[1]

The Pleistocene gravel, which obscures the Permian formations in the northern part of the field, was an important source of water for drilling operations.

In the absence of paleontological data, the Permian-Pennsylvanian contact has been assigned to the top of the Foraker limestone, which occurs at a depth of approximately 1,500 feet on top of the structure (Fig. 1). The "900-foot" gas sand, the Hoy, Whitney, and Hotson oil sands are of Permian age, probably all included within the Stillwater formation. Six oil sands, Campbell, Crews, Garber, Covington, and two unnamed, are in the Ralston group, while two Hoover sands, three sand phases of the Endicott, two Tonkawa sands, and the Layton, all of which are commercially productive of oil and gas, occur in the Sapulpa group. The "Oswego–Big lime" yielded several commercial wells, the oil occurring at irregular levels in the formation.

The Arbuckle limestone, of Cambro-Ordovician age, was the reservoir rock for the major oil accumulation in the pre-Pennsylvanian sediments. Along the west line of the Hartley lease, NW. $\frac{1}{4}$, Sec. 18, which is the structural apex of the Arbuckle limestone, that formation is in contact with the upper Cherokee shales, Lower Pennsylvanian. Sinclair Oil and Gas Company's Belveal No. 29, in the northeast corner of SW. $\frac{1}{4}$ of NE. $\frac{1}{4}$, Sec. 24, T. 22 N., R. 4 W., produced 1,260 barrels from sand in the Tyner shale at a depth of 4,493–96 feet. Other wells in this locality produced small quantities of oil from similar horizons, but were commercially unprofitable. This accumulation on the southwest flank of the structure was beyond the limits of the Ordovician limestone production.

[1] Aurin, Officer, and Gould, *op. cit.*, pp. 794–95.

A minimum thickness of 1,500 feet of sediments is absent in the major pre-Pennsylvanian unconformity on the crest of the structure, and the Permian and Pennsylvanian rocks show a 700-foot reduction from normal thickness as found off structure. Detrital material in what is termed the "erosional zone" on the flank of the Arbuckle limestone structure includes primarily débris of Tyner source. In the wells, which were carefully sampled, no evidence of post-Tyner source materials was found. F. A. Bush, in his analysis of the fauna from the "erosional zone," depth, 4,380 feet, Sinclair Oil and Gas Company's Belveal No. 25, the deep-sand discovery well, assigns them to the lower Carboniferous.[1] Mississippian fauna in rocks of re-worked Simpson lithologic characteristics is indicative of derivation from an island or isolated positive element in the Mississippian sea. This "erosional zone" was, however, retricted to a narrow zone encircling the Mississippian island, as Sinclair Oil and Gas Company's Burns No. 1, NE.$\frac{1}{4}$, SE.$\frac{1}{4}$, Sec. 30, T. 22 N., R. 3 W., two miles south and three-quarters of a mile east of the Ordovician apex, was abandoned in the Mississippian limestone below a depth of 5,400 feet, or 1,200 feet lower than the Cambro-Ordivician limestone on the crest of the structure.

The oil and gas horizons of Pennsylvanian and Permian age are characterized by lenses, irregular bedding, variable porosity, and lateral gradation. In the development of the shallow sands and before the inaugura-

[1] An analysis of the fauna from the erosional zone above the Ordovician limestone in Belveal No. 25, Sec. 24, T. 22 N., R. 4 W., Sample at 4,380 feet:

Prioniodus (?) Sp., *Distacodus* Sp., productid, *Leperditia* Sp., and crinoids.

Conodonts, three of which were found in this well, range through most of the Paleozoic, but in the Mid-Continent area are found in profusion only in the lower Carboniferous. The Caney formation of the Arbuckle area, and the Barnett formation of the San Saba area, contain a rich and varied conodont fauna. The two species found in the Belveal No. 25 are both present in the Barnett Caney fauna, and as far as known, have not been reported from typical Pennsylvanian horizons. One of the forms questionably referred to the genus *Prioniodus* shows evidences of having been much broken, the dentition following the main cusp being gone, as is also the basal extension. Most of the specimens from the Caney and Barnett formations were also broken, however, so this would not necessarily indicate re-worked forms.

Spines and shell fragments indicate the presence of spined productids such as might be expected in either Pennsylvanian or lower Carboniferous sediments. No other specific characteristics were noted.

One completely pyritized ostracod was found. This specimen is referred to the genus *Leperditia*, and very closely resembles specimens of Ordovician (Simpson) age. As the other fossil forms were wholly composed of calcite it is suggested, all evidence being considered, that this specimen is re-worked from the earlier Paleozoic section.

Conclusion: The aggregate fauna indicates Mayes age, at the earliest, though it is possible that these forms are also detrital in the Pennsylvanian sediments.

tion of coring methods, the very irregular occurrence of gas and oil was attributed to the mechanical limitations of rotary-drilling methods, but coring and careful sampling of the Hoover, Endicott, Tonkawa, and Layton sands revealed the conditions here described. Oscillating seas during Pennsylvanian time undoubtedly introduced conditions of deposition which gave rise to the red beds found in the Endicott zone and the very irregular upper surface of the Layton sand.

SURFACE STRUCTURE

The following quotation is from Hager's geologic report:

> The geologic structure is that of a great dome covering some ten square miles. The reversal or dip to the east is at least 190 feet, measured from the highest part of the syncline on the east to the top of the dome. Measured north and south there is a much greater dip.[1]

There is no relation between topography and structure. In accordance with the latest nomenclature and subdivisions of the Enid group, which has been classified since Hager's investigation, the Garber-Hennessey contact indicates the presence of surface structure by making a swing westward around the south end of the field, but the contact is covered beneath a mantle of gravel on the north.

The average normal regional dip is 40 feet per mile toward the west (Fig. 2). West of the meridian and within the area of the Permian Redbeds and since the mapping of the Garber surface structure, core drilling methods have been extensively used in the location of shallow subsurface structures. Those of major importance which have brought about development resulting in the discovery of commercial fields have one closed contour, or more, and the minor surface structural features are generally small southwest-plunging noses.

SUBSURFACE STRUCTURE

The Garber structure aligns in a striking manner with the Thomas-Blackwell-Oxford-Augusta-El Dorado line of folding. The exact and related geologic history of these structures so productive of oil and gas is not known. In the Blackwell field and northeastward granite has been encountered at relatively shallow depths and the presence of a buried range termed the Nemaha Mountains[2] has been postulated. If a sufficiently deep test were drilled in the Garber field, granite, with a greatly reduced thickness of Arbuckle limestone, would undoubtedly be found

[1] Private report by Dorsey Hager, March, 1916.

[2] R. C. Moore, *Bulletin Amer. Assoc. Petrol. Geol.* Vol. 5 (1921), p. 330.

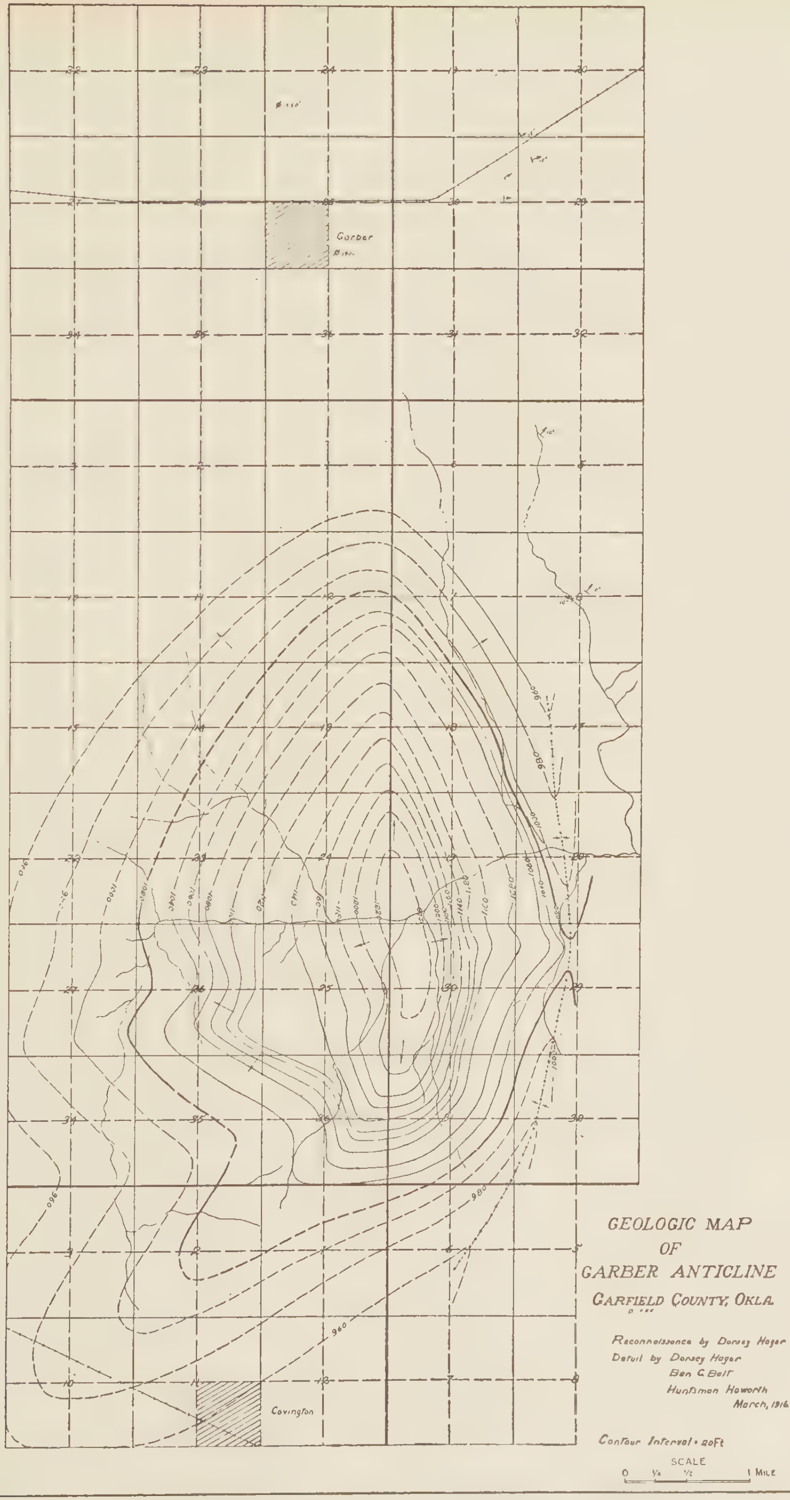


FIG. 2.—Contours mapped on the Garber formation.

at a comparatively high elevation.[1] Assuming the presence of a normal thickness of pre-Pennsylvanian sediments in the Sinclair's Burns No. 1, NE.$\frac{1}{4}$, SE.$\frac{1}{4}$, Sec. 30, T. 22 N., R. 3 W., which encountered the top of the Mississippian limestone at 5,280 feet, and not considering Arbuckle erosion on the crest of the structure, the minimum vertical elevation of the Arbuckle limestone is 2,000 feet.

The "2,100-foot sand" map (Fig. 3) represents the structure at that depth contoured on the best correlative horizons, and in some places represents interpolations due to lateral variation of the marker. The correlations and map are by J. E. Van Dall.[2] The superposition of the surface and 2,100-foot sand structural axes is significant. The apex of the latter is located in the NW. $\frac{1}{4}$, Sec. 18 and the NE. $\frac{1}{4}$, Sec. 13.

The Layton sand structure (Fig. 4) is interpreted with difficulty and this horizon was selected only because of its strategic stratigraphic position and economic importance. The control is also greatly restricted areally. The structural axis strikes northwest, aligning with the Ordovician axis rather than with that of the shallower folding.

The Ordovician or Arbuckle limestone structure map (Fig. 5) is contoured with a 10-foot interval to illustrate a structural interpretation without faults. Burns No. 1, NE.$\frac{1}{4}$., SE$\frac{1}{4}$, Sec. 30, may be east of a fault, but the hypothesis of steep dips and intense folding is favored. The relative terms "top of the Arbuckle limestone" and "Arbuckle limestone structure" are misleading. The map in reality represents the present attitude of the old topographic surface of a buried Ordovician hill which was obliterated finally in Cherokee time, but has since been subjected to recurrent uplift.

The major structural movement involving the Garber structure is believed to be pre-Mississippian. It cannot be assigned to the diastrophism of late Mississippian or early Pennsylvanian, because there is no evidence of erosion of a great thickness of Mississippian limestone, which is the deposition of abnormal thicknesses of chert on the southwest flank and adjacent localities of such folds as Tonkawa and Thomas. Mississippian conodonts[3] are present in the "erosional zone" of Tyner source materials, indicating erosion of Ordovician sediments in Mississippian time. Postulating major elevation and erosion as late Mississippian, only very rapid

[1] June 25, 1928. Hartley 19, SW. cor. NW. $\frac{1}{4}$, Sec. 18, T. 22 N., R. 3 W., has been deepened to a total depth of 5,958 feet, with Arbuckle limestone penetrated 1,267 feet, 4,200 to 5,467 feet, and granite 491 feet, 5,467 to 5,958 feet.

[2] Petroleum engineer, Sinclair Oil and Gas Company.

[3] F. A. Bush, *op. cit.*

erosion would have uncovered the Arbuckle limestone before the submergence by the upper Cherokee sea. The hypothesis of an island of Ordovician rocks in the Mississippian sea is favored. When compared

FIG. 3.—Subsurface structure map contoured on the 2,100-foot sand, Garber district.

with the gentle dips of the Mid-Continent region, the Carboniferous sediments in the field exhibit abnormal attitude, but in no wells drilled to date in the vicinity of the field do the Mississippian rocks indicate the intense folding characteristic of the Ordovician sediments. The question

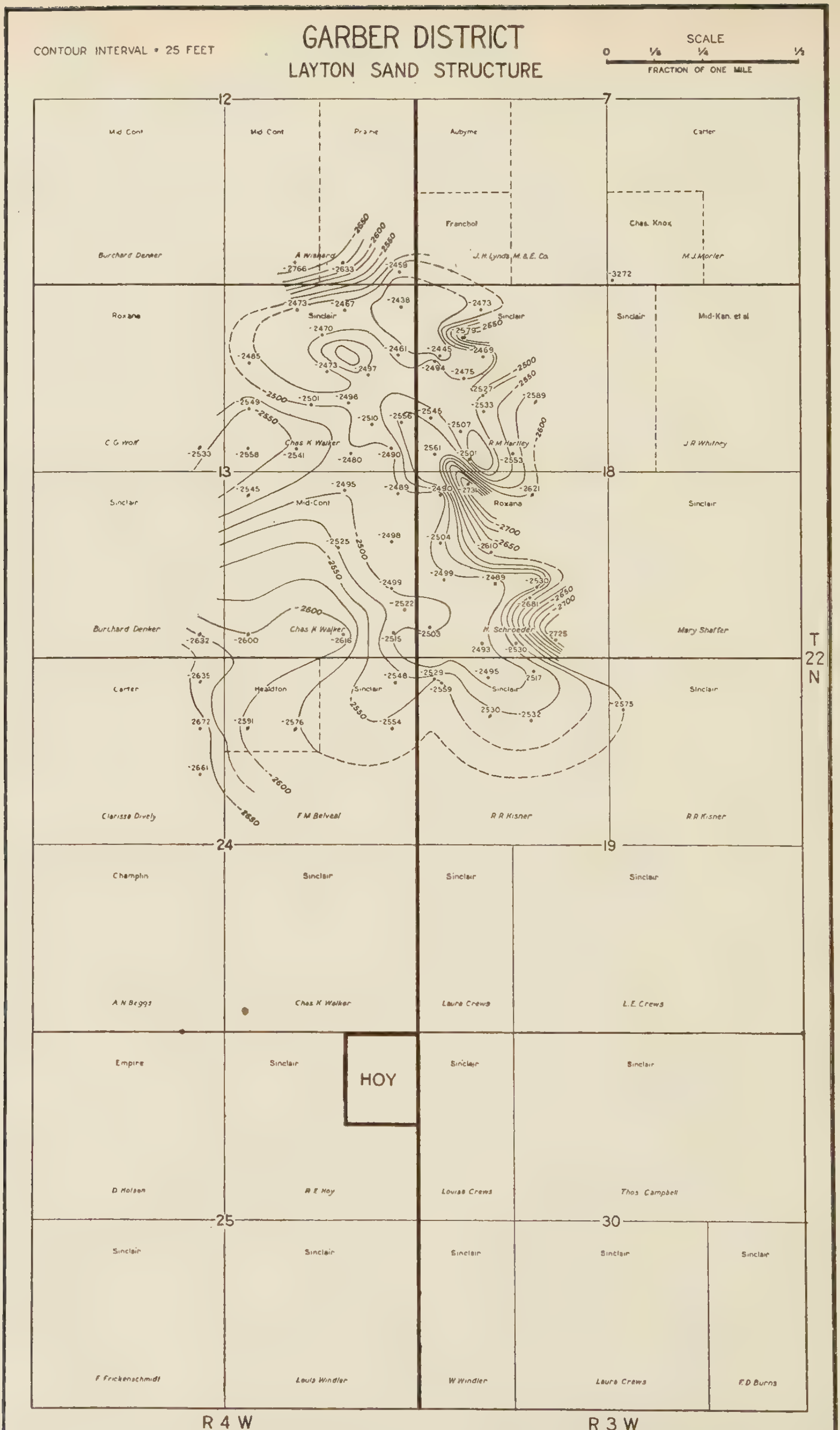

GARBER DISTRICT
LAYTON SAND STRUCTURE
CONTOUR INTERVAL = 25 FEET
SCALE
0 1/8 1/4 1/2
FRACTION OF ONE MILE
12
7
13
18
24
19
25
30
T 22 N
R 4 W
R 3 W
HOY
Mid Cont
Prairie
Aubyme
Carter
Franchot
Chas. Knox
Burchard Denker
A Wishard
J. H. Lynds
M. & E. Co.
M. J. Morler
Roxana
Sinclair
Mid-Kan. et al
C G Wolf
Chas K Walker
R M Hartley
J R Whitney
Mid-Cont
Burchard Denker
H. Schroeder
Mary Shaffer
Carter
Healdton
Clarissa Dively
F M Belveal
R R Kisner
Champlin
A N Beggs
Chas K Walker
Laura Crews
L. E. Crews
Empire
D Holsen
R E Hoy
Louisa Crews
Thos Campbell
F Frickenschmidt
Louis Windler
W Windler
Laura Crews
F D Burns

FIG. 4


GARBER DISTRICT
ORDOVICIAN LIMESTONE STRUCTURE
CONTOUR INTERVAL = 10 FEET
SCALE
FRACTION OF ONE MILE
HOY
T 22 N
R 4 W
R 3 W

FIG. 5

arises whether the Garber structure might not have been an Ordovician hill, formed by forces within the competent basement granites and early Paleozoic limestones, which was buried in the process of deposition of the Mississippian and Pennsylvanian beds, and whether the structure present in the Pennsylvanian and Permian might not be the result of recurrent uplift and differential settling. The latter, however, is believed to be a very minor factor. The senior writer favors such a hypothesis.

The Garber structure tends toward an asymmetric type of fold. The east flank of the 2,100-foot sand structure exhibits an average dip of 200 feet per mile, while the west dip on the opposite limb averages 130 feet per mile. The Ordovician folding is more intense, the dips on the east flank averaging 150 feet per quarter of a mile and those on the west approximating 100 feet per quarter of a mile. The axis of the subsurface folding as mapped on the Hoy sand (1,100-ft.) by L. O. Whyman[1] is located approximately one-quarter mile west of the vertical plane of the Ordovician axis. The crest of the 2,100-foot structure is rather difficult of exact determination. An average axis of the structures as contoured on the Permo-Pennsylvanian horizons takes a more general north-south trend, while the Ordovician axis strikes N. 28° W. This "rotating" of structural axes may or may not be significant. The slight westward inclination of the vertical axial plane indicates that the Garber uplift occurred prior to the introduction of the regional west dip resulting from the Ozark movement. "An asymmetrical fold suggests an overthrust force acting from the direction toward which the axial plane dips; i.e., from the side of the less steeply inclined limb."[2] This is not the status of the Garber axial plane, as its pitch is toward the limb of greatest dips. "The asymmetrical form of a fold might also be attained by an underthrust from the direction of the steeper limb."[3] This type of tangential pressure may have been involved with vertical uplift in the Garber movement and the subsequent Ozark tilting introduced the present pitch of the axial plane. In consideration of the tilting effect of the Ozark uplift, whatever may be the type of force involved, a slight westward shifting of the superimposed structure appears more logical than a westward or southwestward displacement of the underlying structures.

RESERVOIR ROCKS AND OIL ACCUMULATION

The one descriptive term "irregularity" applied to the character, extent, and types of reservoir rocks presents a one-word picture for the Garber field. Lateral gradation, lentils, cross-bedding as observed in

[1] Master of Arts thesis, University of Nebraska, October, 1921.

[2] F. H. Lahee, *Field Geology*, p. 164. [3] Lahee, *op. cit.*, p. 165.

cores, possible sand deposition on the limbs of the fold, and a marked absence of sheet sands proved very baffling to the operators before the advent of the resident geologist, particularly in connection with the development of the sands shallower than 2,300 feet, and were the continued sources of complicated accumulation and correlation problems to the field geologist in the deep-sand campaign. A careful well-log study, however, resulted in a localization of the producing areas in the various sands and facilitated an intelligent development program. No additional generalizations or deductions may be made with respect to the structural attitude and location of the producing areas of the various Permian and Pennsylvanian sands.

The sand features as described in the preceding paragraph promoted an accumulation of oil and gas in numerous horizons characterized by lack of uniform sheet conditions. This irregularity of the reservoir rocks and their contents was further complicated by fissures, or folding crevices, which permitted vertical migration. The circulation was lost in many rotary holes, and wagon loads of cotton-seed meal, hay, and the like failed to restore the circulation. The cause of this trouble was not solution cavities in gypsum or limestone, as the circulation would be lost at depths where only sands and shales were being encountered. In some operations, but not necessarily in the vicinity of lost circulation, the rotary drilling fluid appeared in holes as far as 500 feet from the drilling well.

The writers believe that the Ordovician rocks were the source of a great portion of all the oil in the Garber field, and that vertical migration was a very important factor in its distribution. A survey of the fields of Oklahoma which are geologically associated with Ordovician sediments reveals that those pools which do not have the Viola limestone as cap rock for the "Wilcox" sand are characterized by oil and gas production in large amounts in the overlying Pennsylvanian and Permian rocks, while in a typical "Wilcox" sand pool with its Viola limestone capping the producing sand, the prolific production is in the "Wilcox" sand and shallower production is the exception rather than the general rule. Furthermore, the oil found in the crystalline dolomitic Ordovician limestone at Garber is not the typical Turkey Mountain oil of the Tulsa district with its sulphur odor, but closely resembles in gravity and other physical features the "Wilcox" oil of Tonkawa and Seminole. Truncation of the "Wilcox" sediments during post-Viola and pre-Pennsylvanian time, which was probably associated with recurrent uplift of the Arbuckle mass, permitted subsequent migration of Simpson oil into the older dolomitic limestones, and then still later development of partings in the sediments due to continued uplift and settling facilitated upward migration and hori-

zontal gathering wherever effective reservoir rocks were encountered. Some of the petroliferous accumulations were, of course, indigenous to the Carboniferous rocks, but it is the personal opinion of the authors that it was a minor portion of the gross amount.

The Ordovician oil was found between the crest of the Arbuckle limestone structure (3,060 feet subsea) and the 3,300-foot contour below sea-level.

ANALYSIS OF ORDOVICIAN LIMESTONE OIL, SINCLAIR OIL & GAS COMPANY'S BELVEAL NO. 25, NE. COR. OF SEC. 24, T. 22 N., R. 4 W.

Gravity: 41.8° Bé. Sulphur: 0.16 per cent
Flash: R.T. Pour: 0
B.S.: 0.35 per cent Appearance: green

Cut	Grade	Percentage Crude	Gravity	Flash	Fire	Vis. 100° F.	Vis. 210° F.	Pour
Over to 44	Crude naphtha	45.6	55.4	......	......	......	......	......
44 to 37	Kerosene stock	17.6	39.8	176	195	......	......	......
37 to 32	Gas oil	11.6	34.1	280	335	127	......	35
32 to off	Wax distillate	10.2	29.4	370	430	......	......	80
Bottoms	Cylinder stock	14.0	21.9	525	610	......	170	85
Loss	....	1.0	......	......	......	......	......	......

46.6 per cent U.S. motor gasoline, 55.0° Bé. gravity.

50.5 per cent E. P. gasoline, 54.1° Bé. gravity.

ANALYSIS OF OIL FROM SAND 2,294–2,324 FEET IN DEPTH (UPPER HOOVER). SINCLAIR OIL & GAS COMPANY HARTLEY NO. 7, SW. $\frac{1}{4}$, NW. $\frac{1}{4}$, SEC. 18, T. 22 N., R. 3 W.

Gravity: 42.9° Bé. Sulphur: 0.093 per cent
Flash: R.T. Pour: 0
B.S.: 0.1 per cent Appearance: green

Cut	Grade	Percentage Crude	Gravity	Flash	Fire	Vis. 100° F.	Vis. 210° F.	Pour
Over to 44	Crude naphtha	50.3	55.8	......	......	......	......	......
44 to 37	Kerosene stock	14.2	40.2	174	195	......	......	......
37 to 32	Gas oil	11.5	34.6	270	315	......	......	35
32 to off	Wax distillate	10.0	29.4	370	430	119	......	70
Bottoms	Cylinder stock	12.5	21.5	525	605	......	170	65
Loss	....	1.5	......	......	......	......	......	......

54.7 per cent U.S. motor gasoline, 55.9° Bé. gravity.

60.0 per cent 450 E. P. gasoline, 54.9° Bé. gravity.

Remarks.—Pour too high for S. R. stock; suitable for Bright stock after dewaxing and filtering.

WATER

The first water appeared in Sinclair Oil and Gas Company's Belveal No. 25 at an elevation of 3,279 feet below sea-level. There appeared to be no uniform water level. Probably the high rate of oil recovery caused the water level to rise faster than wells could be drilled. No doubt water-coning took place to a great extent, caused by the high rate of recovery and also influenced by the high porosity of the Arbuckle limestone. The temperature of the oil in many operations was a guide as to water encroachment, a rising temperature indicating that water was approaching. There was no definite critical temperature, water in some wells appearing at a temperature of about 95° F. and in others not until a temperature of 110° was reached. The highest temperature observed by the writers was 125° F. in the case of the Sinclair Oil and Gas Company's Hartley No. 27, northwest corner of Sec. 18, T. 22 N, R. 3 W., although water first appeared at a temperature slightly higher than 100° F. All wells in the Arbuckle limestone eventually went to water.

The Oswego–Big lime series yielded a few spectacular wells of high initial production, but of very short life. Some water appeared in this horizon in the late life of the field, but was undoubtedly due to flooding from the Ordovician, as no water was encountered in the Oswego series during the deep-drilling campaign (Fig. 6).

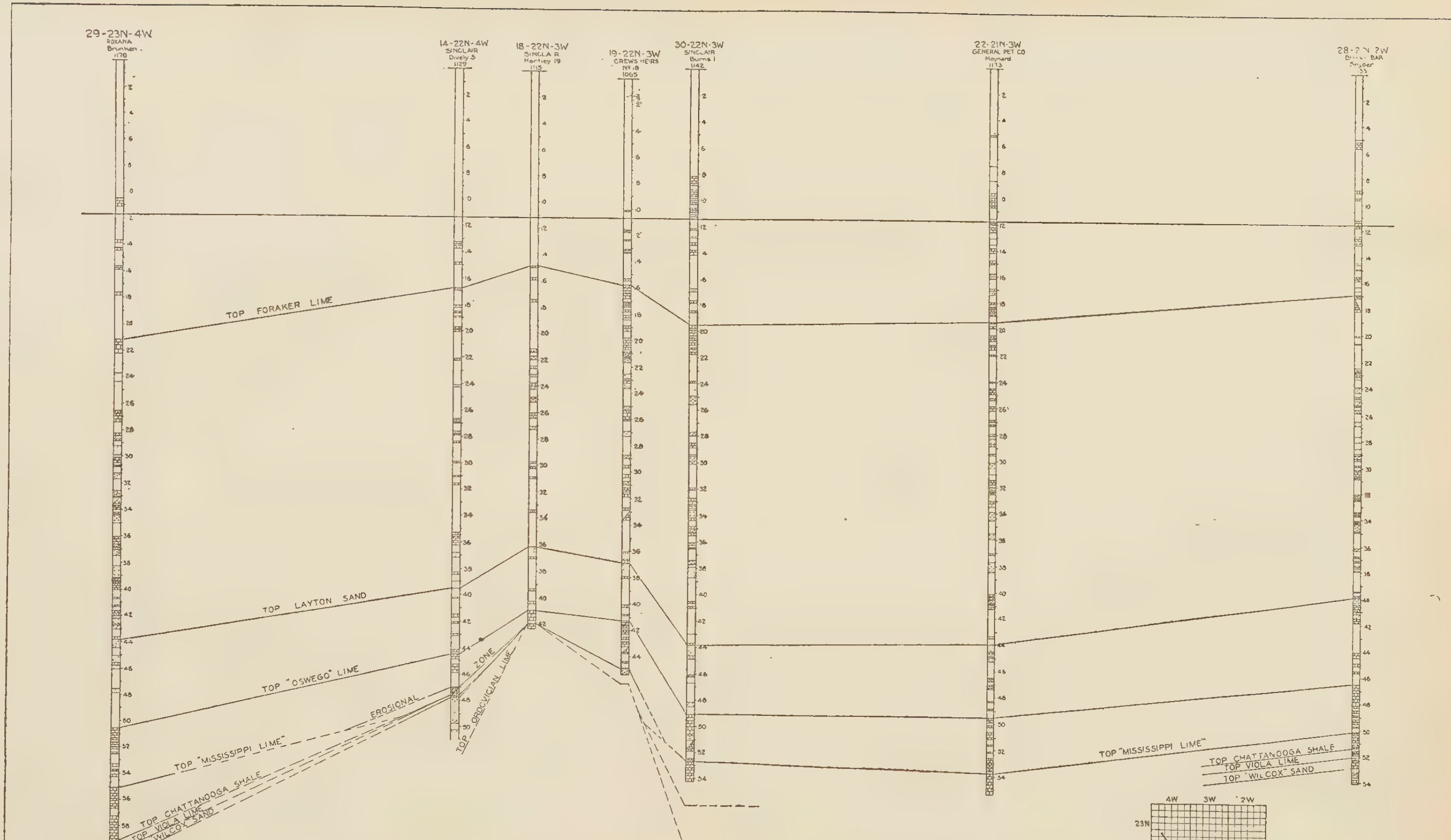
LAYTON SAND WATER ANALYSES BY THE OKMULGEE CHEMICAL & CLINICAL LABORATORY, JULY 23, 1925*

Constituent	Grams per Liter	
	Sample 1	Sample 2
Silica	0.080	0.030
Iron and aluminum oxides	0.270	0.300
Calcium	19.92	17.70
Magnesium	2.442	2.541
Sodium	64.61	73.62
Chlorine	141.80	152.10
Sulphate	0.347	0.3196
Specific gravity	1.1595	1.1636

* Samples received from Sinclair Oil and Gas Co., July 20, 1925.

Sample No. 1 marked "Sample of water from well No. 18, Crews Heirs, Sec. 19, T. 22 N., R. 3 W., Garber field. Sample from sand 3,700–3,710 (Layton?). Samples July 3, 1925, by R. M. Carr."

Sample No. 2 marked "Sample of water from Sinclair O. & G. Co.'s Burns No. 1, center NE. ¼ of SE. ¼, Sec. 30, T. 22 N., R. 3 W., Garber field. Top sand, 4,385; water from 4,385 to —— (Layton). Sampled by R. M. Carr, June 15, 1925."



GARBER DISTRICT
STRATIGRAPHIC CROSS SECTION

The waters in the Ordovician limestone were characterized by high secondary salinity and high total solids. The sulphate content was comparatively low. These features are in contrast to the waters found in the Ordovician limestones of Kansas, which are low in total solids, averaging 30 to 50 parts per thousand, and high in sulphate content.[1]

ARBUCKLE LIMESTONE WATER ANALYSES BY THE TULSA LABORATORIES, INC.

Constituents	Mg. per Liter	Percentage of Reactive Value
Sodium	60,733	33.51
Magnesium	2,791	2.91
Calcium	21,453	13.57
Chloride	139,496	49.89
Sulphate	352	0.09
Bicarbonate	43	0.03
Total solids	224,868	

PROPERTIES OF REACTION IN PERCENTAGES

Primary salinity	67.02
Secondary salinity	32.94
Primary alkalinity	0.00
Secondary alkalinity	0.06

Sampled by R. M. Carr, petroleum engineer, Sinclair Oil and Gas Company, Cosden-Marland No. 41, Sec. 13, T. 22 N., R. 4 W. Depth, 4,383 feet, flowing daily approximately 10,000 barrels of water.

Constituents	Mg. per Liter	Percentage of Reactive Value
Calcium	23,315	13.34
Magnesium	3,076	2.89
Sodium	67,701	33.76
Chloride	154,336	49.89
Sulphate	339	0.09
Bicarbonate	43	0.03
Total		100.00

PROPERTIES OF REACTION IN PERCENTAGES

Primary salinity	67.52
Secondary salinity	32.44
Primary alkalinity	0.00
Secondary alkalinity	0.06

Sampled by R. M. Carr, petroleum engineer, Sinclair Oil and Gas Company's Belveal No. 25, NE. cor., Sec. 24. Depth 4,430–34 feet. Water from gas trap. Making 40 barrels water daily.

[1] R. L. Ginter, Tulsa Laboratories, personal communication.

CRINERVILLE OIL FIELD, CARTER COUNTY, OKLAHOMA[1]

SIDNEY POWERS[2]
Tulsa, Oklahoma

ABSTRACT

The Crinerville oil field, near Brock, Carter County, Oklahoma, occurs on a surface anticline in Pennsylvanian strata on the west side of, and faulted against, the Criner Hills. The reverse dip of 15° on the northeast side of the anticline disappears under a large part of the anticline in shales within 900 feet of the surface. Production comes from Pennsylvanian oil sands which overlap a truncated portion of the original Criner Hills of Ordovician limestone, now buried at a depth of more than 1,000 feet. The oil originated in the Pennsylvanian shales, and a small quantity migrated laterally into the Ordovician. The field was opened in January, 1922, and has produced between 1,000 and 1,500 barrels a day ever since. The total production to June 30, 1927, was slightly more than 2,300,000 barrels.

INTRODUCTION

LOCATION

Crinerville oil field, named from a schoolhouse, is 2 miles southeast of Brock and 7 miles southwest of Ardmore. The field extends southeast from the center of the south line of the SW. $\frac{1}{4}$ of Sec. 17, through the E. $\frac{1}{2}$ of Sec. 20 and the E. $\frac{1}{2}$ of Sec. 28, to the center of Sec. 34, T. 5 S., R. 1 E. By July, 1927, $5\frac{1}{2}$ years after the discovery, 139 oil wells (7 now abandoned), 3 gas wells (2 now abandoned), and 46 dry holes had been drilled. The depth of production ranged from 845 to 2,200 feet. The initial production averaged about 50 barrels, and the settled production, 15 barrels.

This field is located 15 miles southeast of the southeastern end of Healdton and 10 miles southeast of the southeastern extension of Hewitt. It lies in a belt parallel to the Criner Hills and at a distance ranging from one-quarter to three-quarters of a mile from their southwestern flank. It is 15 miles south of the Arbuckle Mountains.

GEOLOGY

Geologically, the field is located on an inlier of the Glenn and Hoxbar formations of Pennsylvanian age, bounded on the west and south, and

[1] Presented by title before the Association at the Tulsa meeting, March 26, 1927. Manuscript received by the editor, July 28, 1927. Published by permission of the Amerada Petroleum Corporation. Reprinted from *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 10 (October, 1927), pp. 1067–85.

[2] Consulting geologist, Amerada Petroleum Corporation.

in part on the north, by the unconformable Trinity sand of Cretaceous age. The Pontotoc formation of Permian age rests on the Glenn north of the field. The Criner Hills, against which the Glenn formation is down-faulted, are a fragment of the ancient Criner Hills, or possibly of the ancient Wichita Mountains, and consist of complexly folded and faulted Ordovician limestones, bounded on the east by faulted fragments of most of the formations known in the Arbuckle Mountains, 15 miles farther north. Production comes from sands within the Glenn formation which overlaps the ancestral Criner Hills.

The areal geology has been mapped by Taff,[1] Goldston,[2] and Tomlinson.[3] Other pertinent geological reports are by Birk,[4] Girty and Roundy,[5] Moore,[6] and Bullard.[7] The accompanying map (Fig. 1) is after Tomlinson.

DEVELOPMENT

The Crinerville anticline seems to have been known since about 1916, but neglected as a possible oil prospect. It was discovered by the Amerada Petroleum Corporation about June 1, 1920, and the leasehold was secured in 1920 and 1921, giving a solid block except for fee lands of Westheimer & Daube and F. E. Watkins.

The discovery well, Sammy Baptiste No. 1, was located by E. L. DeGolyer near the center of the SE. $\frac{1}{4}$ of Section 20, on the west side of the small closure in contours of the surface geology shown in Figure 2. It was commenced in December, 1921, and the first sand was struck at 1,321 feet, January 15, 1922. The first sand was only 4 feet thick and good for about 50 barrels. A second sand at 1,371 feet was good for 20 barrels; and a third, from 1,564 to 1,629 feet, made 90 barrels. This well flowed from

[1] J. A. Taff, "Preliminary Report on the Geology of the Arbuckle and Wichita Mountains," *U. S. Geol. Survey Prof. Paper 31*, 1904.

[2] W. L. Goldston, Jr., "Differentiation and Structure of the Glenn Formation," *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 6 (1922), pp. 5–23.

[3] C. W. Tomlinson, unpublished map dated April, 1926; also *Oklahoma Geol. Survey Bull. 40*, 1927.

[4] R. A. Birk, "The Extension of a Portion of the Pontotoc Series around the Western End of the Arbuckle Mountains," *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 9 (1925), pp. 983–89.

[5] G. H. Girty and P. V. Roundy, "Notes on the Glenn Formation of Oklahoma, with Consideration of New Paleontologic Evidence," *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 7 (1923), pp. 331–49.

[6] R. C. Moore, "The Relation of Mountain Folding to the Oil and Gas Fields of Southern Oklahoma," *ibid.*, Vol. 5 (1921), pp. 32–48.

[7] F. M. Bullard, "Geology of Love County, Oklahoma," *Oklahoma Geol. Survey Bull. 33*, 1926; "Geology of Marshall County," *Bull. 39*, 1926.

the third sand for 3 years before it was put on the pump. These three are the principal sands in Section 20, the wells being completed so that they produce either from the first two together by setting a perforated liner through the first sand, or else from the third sand. Two deeper oil sands,

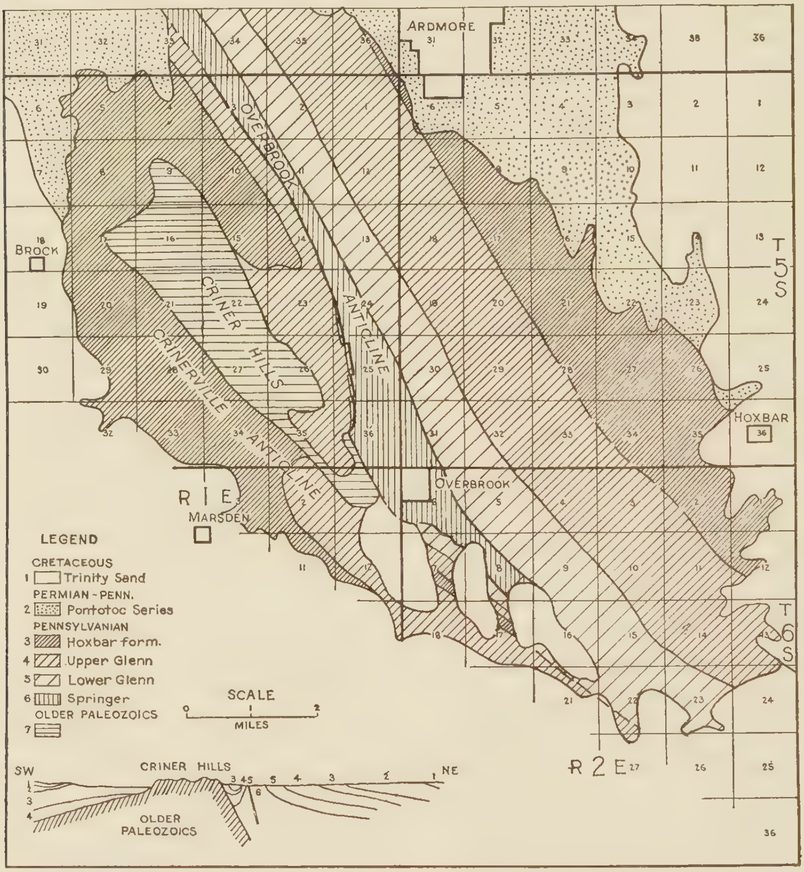


FIG. 1.—Areal geological map of the Criner Hills, showing the relation of the Crinerville anticline to the horst of older rocks. (Geology by C. W. Tomlinson, Amerada Petroleum Corporation, and others.)

called the fourth and fifth, occur locally on the northern and western flanks of the anticline.

Soon after the discovery of the field, Westheimer & Daube completed a well in Section 21 in the top of the Ordovician, with "sand" at depths ranging from 1,585 to 1,682 feet, flowing 250 barrels. The Pennsylvanian

sands were not productive. Two offsets to this well made 600 and 1,100 barrels, respectively; but the well highest in the producing horizon drained the oil, and all three wells declined rapidly and were abandoned within a year. As the oil was exhausted the sulphur water increased. With the

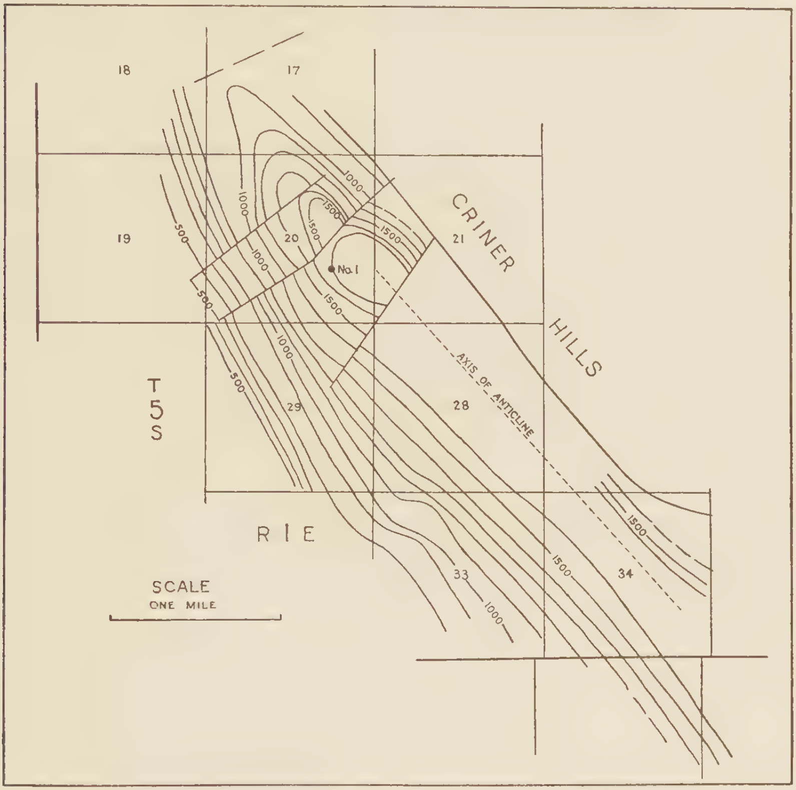


FIG. 2.—Structure contours, above sea-level, of the surface geology, Crinerville anticline. Contour interval, 100 feet. Datum, sea-level. The location of the discovery well is shown. (Geology by R. A. Birk and C. J. Wohlford, for the Amerada.)

exception of one gas well, other near-by wells drilled into the Ordovician found only sulphur water with more or less sulphur gas.

The field was a disappointment until large wells were found in the north half of Section 20 in 1923. By 1924, production seemed to be defined by dry holes. A hand drill was used to locate the axis of the anticline at the surface in Sections 28 and 27, and a well was drilled on the Clay farm, in the center of the west line of the NE. ¼ of Section 28 on this axis.

Oil was found in a sand from 1,074 to 1,083 feet in Clay No. 1, on October 27, 1924. The well flowed 230 barrels steadily and opened the extension in Section 28. The main producing horizon is the second sand. A few wells yield oil from a sand intermediate between the first and second of the original field, but not present there.

A second extension of production, in Section 34, near the center of the section, was made in May, 1925, but the wells are very small.

TOPOGRAPHY

Topographically, the eroded peneplain of the Criner Hills has an elevation of 1,000 feet above sea-level, or 150 feet above the secondary peneplain on the Pennsylvanian and younger rocks. The dissection of the latter peneplain has produced a relief of 100 feet.

Vegetation is an excellent guide to geology. Short grass only grows on the barren Ordovician limestone hills. The Pennsylvanian shales support tall grass, and ridges formed of the few limestone beds are marked by rows of bushes and tall weeds. The Permian and Cretaceous sandstone are covered with a dense growth of "blackjack" oak.

ACKNOWLEDGMENTS

The writer is indebted to R. A. Birk and Miss Dollie Radler for assistance in preparing this paper, and to B. H. Harlton for paleontological determinations. C. W. Tomlinson, who has made a careful study of the Glenn formation, has kindly permitted the use of his determinations and areal map.

GEOLOGIC HISTORY

Within the Arbuckle Mountains there are exposed pre-Cambrian granites and the well-known section of Paleozoic sedimentary rocks extending upward through the Caney shales of Mississippian age and through part of the Glenn and other formations of Pennsylvanian age. The most important group of rocks is that of the Ordovician limestones. Structural conformity marks the entire pre-Pennsylvanian section when considered as a whole, but there is an unconformity above the Hunton group (Devonian at the top) which marks undulating folding of the entire region. This folding is known best on the north flank of the Arbuckle Mountains, at Seminole and other oil fields.

Fragments of the formations in the Arbuckle Mountains, from the Arbuckle at the base through to the Sycamore limestone at the top, are exposed in the Criner Hills, the older rocks being on the southwest side. Faulting has masked the relationship of different formations, but structural conformity is supposed to exist to the top of the Woodford. Strata representing all the members of the Glenn formation as defined by Gold-

ston occur on the east side of the hills, but the base of the section is not exposed. Subsequent work has led to a reclassification of this section: Springer formation at the base, Otterville (Wapanucka) limestones, Glenn formation, consisting of Cup Coral and Deese members and Hoxbar formation, at the top, overlain farther west and underground by sedimentary rocks of Upper Cisco age.[1]

On the west side of the Criner Hills, the wells at Crinerville start in the Deese member of the Glenn on the axis of the anticline and in the Hoxbar formation on the flanks, and find Ordovician limestones below the Deese. Cuttings from wells show that the buried Ordovician rocks are Arbuckle on the east; but both the Simpson formation and Viola limestone may occur under the field. This unconformity proves that the folding and faulting of the ancestral Criner Hills took place after the deposition of the Springer formation and before the deposition of the Deese member of the Glenn. The writer believes that the uplift is a part of the ancestral Wichita Mountains, and that these mountains were once continuous as far southeast as Gainesville, Texas, but that granite was exposed in a few places in the portion now concealed by Permian and late Pennsylvanian rocks.

Coarse conglomerates in and directly beneath the Otterville limestone and in the Cup Coral member of the Glenn on the east side of the Criner Hills[2] fix the time of the uplift of the ancestral Criner Hills and Wichita Mountains. The pebbles are largely of Ordovician limestone; there are none of granite because whatever granites were exposed in the Wichitas were too far distant. It is evident that these conglomerates came from the nearby ancestral Criner Hills and the area on the west—the Wichita Mountains. Finally this region was leveled and submerged by the upper Deese. Conglomerates have not been found at the unconformity under Crinerville on the west side of the hills. Arkose occurs in conglomerates in the uppermost Deese and in the Hoxbar in exposures east of the Criner Hills.

Both the northern Arbuckles and the Wichitas were folded early in the Pennsylvanian. Refolding and faulting occurred several times during the Pennsylvanian and at the close of this period. The ancestral Criner Hills were faulted again late in the Pennsylvanian. These faults on the west and north sides of the present hills were normal with a downthrow of at least 1,000 feet on the west and north. After this faulting compres-

[1] Sidney Powers, "Age of the Folding of the Oklahoma Mountains—the Wichita, Arbuckle, Ouachita Mountains of Oklahoma and Llano Burnet and Marathon Uplifts of Texas," *Bull. Geol. Soc. Amer.*, Vol. 38, 1927.

[2] Personal communication from C. W. Tomlinson.

sion squeezed the plastic Pennsylvanian shales against the resistant block of limestone and made the anticlinal fold seen at the surface at Crinerville. This folding probably occurred at the time the Glenn basin at Ardmore was compressed into long anticlines and synclines.

Sedimentation recommenced before the Permian. The Pontotoc arkoses and conglomerates were deposited late in the Pennsylvanian or early in the Permian on the flanks of the Arbuckles and on the northeastern flank of the Wichitas, the ancestral Healdton, Hewitt, and Criner hills. Permian Red-beds overlie the Pontotoc. Another uplift folded the Red-beds into gentle flexures, and some of the anticlines of this generation overlie the older ones. The folds in the Red-beds cannot be mapped with satisfaction because of cross-bedding and scarcity of exposures. These sandstones and shales covered an area of considerable relief in which the hills were anticlines. It seems remarkable that these hills are not reflected more distinctly because there are only 300 feet of Red-beds under Healdton, contrasted with 2,400 feet under an area 3 miles north of this field.

Trinity sand, of Lower Cretaceous age, was deposited throughout most of southern Oklahoma, and probably on the Criner Hills. The character of folding of the Cretaceous is indicated in the Preston anticline of Marshall County, yet the Cretaceous beds do not reflect folding in the older rocks in Cooke County, Texas.

Later uplift has elevated the peneplain of the Arbuckles and the antecedent Washita River. Still later uplift has elevated the lower peneplain of the softer rocks. It is difficult to connect the anticlinal hills of Healdton, Hewitt, Velma, and other fields with differential uplift in post-Cretaceous time because most of the anticlines in the Mid-Continent region have been hills at some time since the Ordovician.

STRATIGRAPHY

EXPOSED BEDS

The Crinerville anticline was mapped on limestone and sandstones of the Hoxbar formation on the flanks and the Deese member of the Glenn on the top. According to stratigraphic measurements by R. A. Birk and C. J. Wohlford for the Amerada, the thickness of the Hoxbar, measured from the base of the lowest to the highest bed exposed, is 1,180 feet in Section 20 and 1,250 feet in Sections 28 and 29, and the thickness of the Deese exposed in Section 34 exceeds 200 feet. The dip on the southwest flank is about 15 degrees and on the northeast flank 20 degrees. The thickness of the section is difficult to measure on account of faulting, but these measurements are confirmed by well logs.

UNEXPOSED BEDS

Sammy Baptiste No. 1, the discovery well, started in the limestone at the base of the Hoxbar, found a water sand at 400 feet, and a gas sand at 1,000 feet. This section is similar in all the wells in the field, but there are generally at least two water sands and some sandy shales and thin limestones. Several sands and thin limestones between 1,000 and 1,063 feet which produce in two wells in Section 17 are called the "heavy oil series" because they carry a little oil of 20° Bé. gravity. These sands are separated by 240 feet of shale from the main oil series below. The first and second oil sands, at a depth of more than 1,300 feet, are 20 to 50 feet apart, and the third is 150 feet or more below the second. The first thick limestone is, as a rule, the Ordovician, and it may be found at any depth below the heavy oil series, although as a rule it is covered by the first and second sands. Away from the field a section of more than 1,000 feet of shale and water sands has been found below the third sand. One well in Section 28 on the edge of production was drilled in solid limestone from 1,492 to 3,930 feet. D. K. Gregor and V. V. Waite in private reports described this limestone as Simpson.

Correlations are made tentatively on the heavy oil series and definitely on the first oil sand, but they are very difficult to make, even though all wells are drilled with standard tools. The sands are not overlain by a hard cap rock or "shell," and in some places are not recognized. In Section 21 and elsewhere the sands merge into brown shales recorded in the well logs as "Red-beds."

Changes in thickness and composition of the sands, both of the water sands above and oil sands below, are rapid. The oil sands were deposited by progressive overlap on the older, truncated limestones, and the sands and shales filled the irregularities on the erosional surface. The large divisions of the section, thick shales above and alternating shales and sands below, do not vary greatly in thickness, but the number of water sands increases away from the field so that correlation for a long distance on lithologic grounds is impossible.

CONDITIONS OF DEPOSITION

The ancestral Criner Hills constituted a land area of low relief at the time of deposition of the upper part of the Deese over them. The brown or red shales into which the sands merge on the east are believed to have been deposited near or above sea-level and to represent the muds exposed to aerial oxidation. Similar relationship of sands and red or brown shales is very common on the anticlines in the Mid-Continent region

and may also be observed in the oil mines of Pechelbronn, France. Oil is seldom found where the sand merges into brown shale.

SURFACE STRUCTURE

Folds in the Paleozoic section of southern Oklahoma are essentially of the anticlinal type, as throughout the Mid-Continent region where the anticlines are elevated from a more or less common level without corresponding synclines with closure. The axes of the folds extend uniformly northwest and southeast. Crinerville is one of these folds, but it might be termed a "geological accident" because of its superposition on truncated Ordovician limestones and its faulted relationship to the present Criner Hills with downthrown beds dipping steeply toward a normal fault, and also because the fold dies out at a shallow depth. The other anticlines are either sharp folds in a thick Pennsylvanian section or else broad folds with subsidiary domes and saddles over buried hills of Ordovician limestone, the detailed structure reflecting buried topography.

The surface-structure contour map of the anticline (Figure 2) is based on planetable mapping of limestone outcrops. In order to confirm the presence of a northeast dip where there are no exposures, several excavations were made in the Pennsylvanian shales at the faulted contact with the Criner Hills, and two lines of holes were drilled across the axis of the anticline. Instead of drag dips, steep northeast dips were found in the shale at the fault plane.

The anticline is an asymmetrical fold which starts in Sec. 2, T. 6 S., R. 1 E., as a nose cut off on the south by a fault against the Criner Hills. The axis runs parallel to the fault at the west side of the Criner Hills as far as the center of the west line of Sec. 17, T. 5 S., R. 1 E., where it is cut off by a fault. North of this point the limestones bend broadly around the Criner Hills and do not seem to be affected by the Crinerville fold. The length of the fold is 4 miles.

Closure was not found along the anticlinal axis, though there is almost a closure in the southeast corner of Section 20. In Section 34 the axis plunges more steeply northwest and older beds occur at the surface.

Faulting is very common at the surface, as will be described later. The minor faults die out at a shallow depth.

SUBSURFACE STRUCTURE

The structure on the second oil sand is shown in Figure 3. There is a general southwesterly dip, with high areas in Sections 20, 28, and 34 separated by synclines. The cross-faults at the surface (Fig. 2) are not clearly

shown at this horizon, but those with the largest throw may extend to this depth. Another fault is shown in Sections 21 and 17 parallel to the Criner Hills because the Ordovician was found in the easternmost well 400 feet higher than in the offset on the west in Section 21. The correlations are too unsatisfactory to prove that this fault cuts the Pennsylvanian.

The eroded and folded surface of the Ordovician (Fig. 4) resembles the structure of the second sand, but the west slope is much steeper and there is a more pronounced flattening in the E. ½ of Section 20. The Pennsylvanian sands overlap this surface, and each has a separate shore line against it (Fig. 5). The highest, or first, sand has its shore line on the eastern edge of the field in Sections 28 and 34. Low hills and valleys, with a local relief of 50 feet or less, have been found on the surface of the limestone, and some of the hills project above the pay sand in the southeast corner of Section 20, the SE. ¼ of Section 28, and center of Section 34 (Fig. 3). The larger valleys underlie those shown on the second sand map. This relief is in places so local that both in Section 28 and in Section 20 a five-spot well in the center of a rectangle of producers 400 and 460 feet apart was a dry hole because the lime projected above the level of the sand.

The distribution and structure of the oil sands which rest against and on the Ordovician unconformity are determined by the configuration of this surface in upper Deese time. Explanation of the irregularities in the surface of the Ordovician is found in the lithology of the older rocks. The folding which made the anticline in the upper beds tilted all the rocks toward the southwest at an angle of about 10°.

FAULTING

The gently curved fault line which separates the Pennsylvanian and Ordovician at the surface slopes away from the hills at an angle of about 70°. The sinuous plane in many places follows the strike of the steeply tilted limestones, and this fact makes the contact appear as though the Pennsylvanian shales had slid away from steep-sided limestone hills. Drilling has, however, proved the presence of a major fault with a drop of about 1,000 feet. The fault seems to turn at right angles in Section 17 and to continue northeast; farther east it makes two more similar turns to encompass the north end of the hills, or else there are two sets of faults.[1]

[1] C. W. Tomlinson believes that these contacts on the northern edge of the Criner Hills are unconformities instead of faults, or else that the faulting occurred before Deese sedimentation (letter of October 19, 1926).

It is possible that at these corners short faults extend between the Pennsylvanian outcrops, and therefore cannot be found.

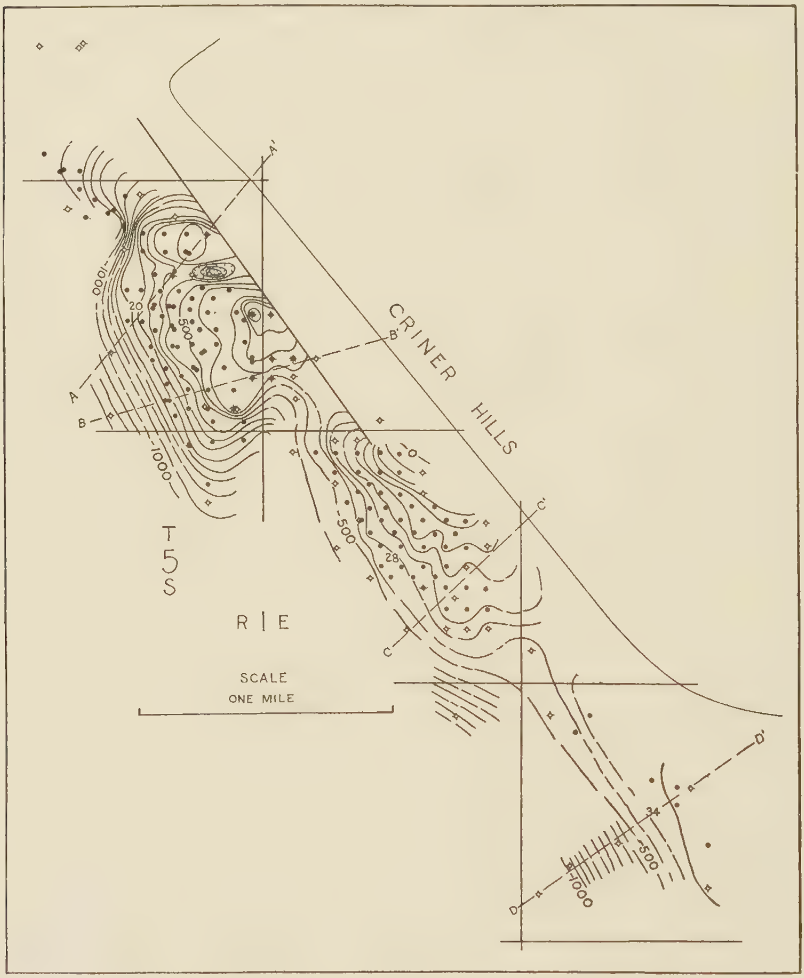


Fig. 3.—Structure contours of the Crinerville oil field, below sea-level, on the "second" oil sand. Contour interval, 50 feet. Cross sections are shown in Figure 5. The anticline at the surface cannot be recognized at this horizon, depth 900–1,800 feet. (Geology by Dollie Radler, for the Amerada.)

An explanation of these sharp turns is that intersecting sets of faults were formed when the hills were folded in early Pennsylvanian time and that right-angled blocks gave way simultaneously in the later faulting so

that the trace of the fault in the Pennsylvanian actually turns sharp angles without cross-fractures. In support of this view it may be pointed out that the cross-faults in the present Criner Hills (marked by valleys) do not cause offsets in the trace of the major fault plane.

South of the oil field the major fault turns and extends north and south and cuts off the anticline in Secs. 1 and 2, T. 6 S., R. 1 E. Still farther south the Pennsylvanian beds dip away from the fault at an angle of 15° and there is no anticline. No buried extension of the Criner Hills on the southeast has been found by wells.

Drilling has shown a buried fault in Sections 21 and 17, as previously stated, with a downthrow on the west of 350 feet in a distance of 450 feet in Section 21. No evidence of this fault is found at the surface in Section 21 or underground in Section 28 on a projection of the fault plane toward the southeast. Moreover, the log of the well with shallow Ordovician limestone (penetrated for 130 feet) can be correlated with no fault in the Pennsylvanian. Wirt Franklin drilled twin wells west of the center of Section 17. The east well had Ordovician at 1,795 feet and the western no Ordovician at 1,905 feet, where the hole was lost. The Magnolia dry hole, 1,000 feet west, found the limestone 1,340 feet deeper. The fault has been drawn to extend between these wells as shown in Figure 4.

On the map of surface structure contours (Fig. 2) several cross-faults may be seen, each with a downthrow on the northwest. The maximum vertical displacement along the major faults is 250 feet. Innumerable small faults occur which cannot be shown except on a large-scale map, and many other faults probably exist in the area of no exposures. The major faults have their greatest displacement where there is the greatest bedding of the rocks (at the crest of the anticline), and most of the faults practically die out at a depth of about 900 feet. In these particulars they resemble the faults at Salt Creek, Wyoming.

At least two of the major faults are connected with cross-fractures in the Criner Hills. Near the center of Section 21 there is asphalt in the Ordovician limestones which must have come from the Pennsylvanian, but it is not along a fault. It is probable that at the time the block on the western side of the present Criner Hills sank, the cross-fractures in the Ordovician moved sufficiently to break the overlying Pennsylvanian.

Well logs show that the minor faults do not affect the oil sands. There is a sharp syncline in the southwest corner of Section 21 beneath the surface fault, and several dry holes have been drilled here, but there is no fault between the three wells in the SW. $\frac{1}{4}$ of the SW. $\frac{1}{4}$ of Section 21, and there does not seem to be a fault north of the dry hole in Section 29.

A closed syncline on the oil sands marked by a dry hole in the NE. ¼ of Section 20, shown in Figure 3, underlies a surface fault and may be

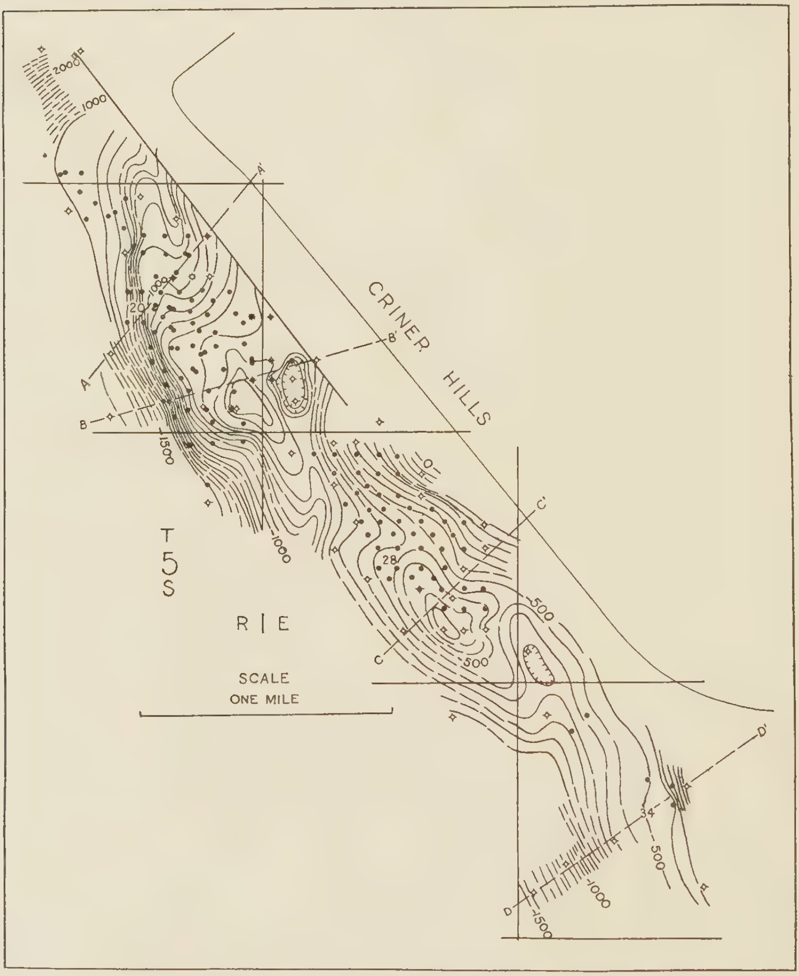


FIG. 4.—Structure contours of the Crinerville oil field on the eroded surface of the Ordovician, below sea-level, at a depth underground of 1,200–2,500 feet in the producing area. There is no hill on this eroded surface underlying the anticline at the surface of the ground. Oil was produced from the Ordovician in four wells surrounding the NE. cor., SE. ¼ of SE. ¼, Sec. 20. Contour interval, 50 feet. (Geology by Dollie Radler.)

due to faulting. A northeast-southwest line of dry holes and small wells near the center of the N. ½ of Section 20 coincides with another fault, and

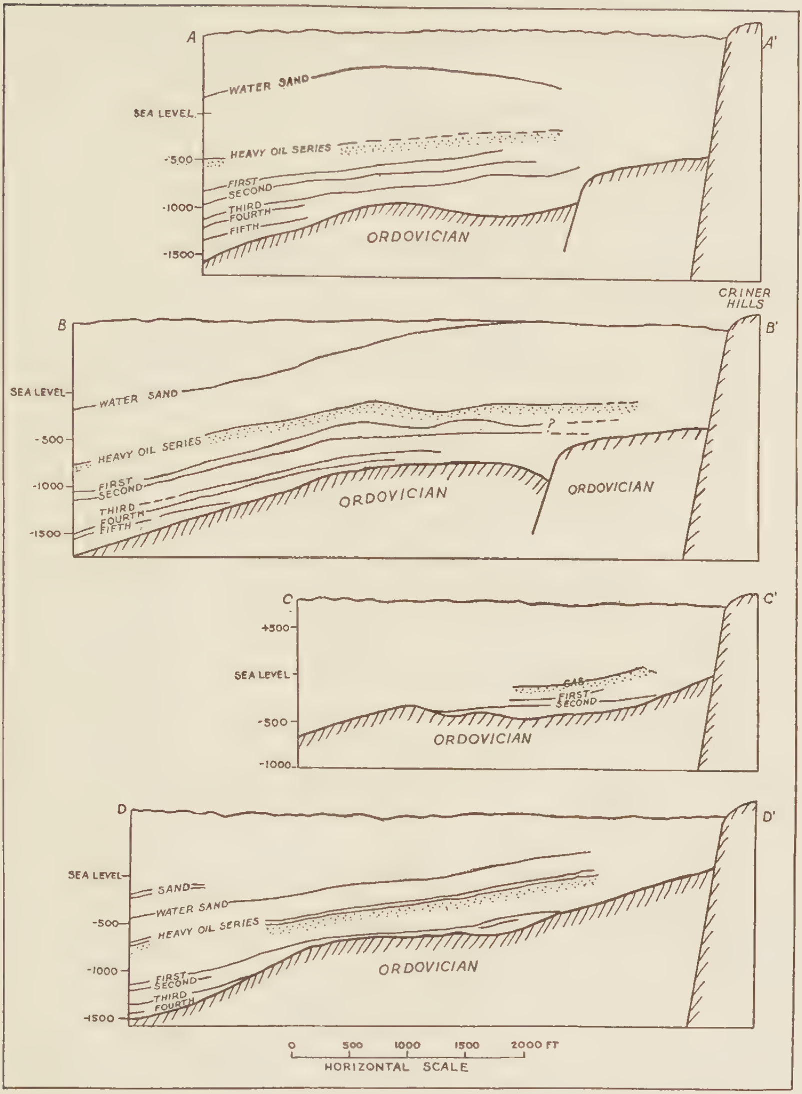


FIG. 5.—Cross sections of the Crinerville oil field showing that the anticline disappears in the Pennsylvanian strata and that the eroded surface of the Ordovician is irregular. The subsidiary fault block west of the main Criner Hills fault was a topographic ridge during the deposition of the Pennsylvanian. Location of the sections shown on Figures 3 and 4. Length of section *A–A′*, one mile, and depth, 2,500 feet. Vertical scale in feet.

oil accumulation may be affected by it. The dry holes either miss the sand or find small showings of oil with salt water in contrast to good wells on either side.

Both the anticline and the minor faults disappear within 900 to 1,000 feet of the surface by flowage of the shale. It is clear that the anticline is not due to settling or compacting of the shales—one of the theories advanced to account for the anticlinal folds in northern Oklahoma. It was made by the same tangential compression which squeezed the Glenn sediments of the Ardmore basin into tightly folded long anticlines and synclines. Intensity of folding seems to increase upward, but this appearance may be due to buckling against the major fault plane. There are no drag dips in the Pennsylvanian at this fault, but instead there are steep dips toward the plane. The minor cross-faults may have been caused by this buckling.

RESERVOIR ROCKS

The reservoir rocks, with the exception of the Ordovician limestone in four wells which produced from this horizon, are thin fine-grained sands which feather out or merge into brown shale where they intersect the unconformable surface of the older limestones. The productivity of wells has not been as great as in similar fields of southern Oklahoma, comparing sands of equal thickness. This may be due to shale content. There are no "shells" or cap rocks over the sands, and the change from shale to sand in cable-tool wells is noticed, as a rule, only from cuttings. During Pennsylvanian sedimentation no sandstone was exposed in the Criner Hills, and the nearest source for quartz grains must have been many miles away; hence the oil sands probably represent material derived from the washing of sandy muds at or near sea-level in a shallow sea free from well-defined beaches and bars and entirely free from pebbles derived from the underlying limestone.

Volume of gas and water pressure are both low. The gas wells have yielded less than 5,000,000 cubic feet a day. Water has not been troublesome except in one well drilled into the Ordovician, from which a pocket of sulphur gas caused an artesian flow of sulphur water for several days.

Pennsylvanian shales are evidently the source rocks, and in this field, where the sands are more or less lenticular, it seems logical to assume the generation of oil locally.

RELATION OF ACCUMULATION TO STRUCTURE

Healdton, Hewitt, and Crinerville are all examples of buried Ordovician hills overlain by Pennsylvanian sands. Production has been found indigenous within the older rocks in the first two fields, and especially

at Hewitt. The best production in each field comes from the Pennsylvanian quartz sands above the older quartz-free limestone. The buried hill has determined the location of the overlying anticline in each field, and the Pennsylvanian accumulation is anticlinal.

Crinerville is an excellent example of accumulation up the dip near the feather edge of sands. Similar conditions are described for some of the Ohio fields. The arrangement of oil, gas, and water within the sands accords with the structural theory of accumulation. Each of the five numbered sands, and, in Section 28, one intermediate sand, carries oil in a belt between its edge on the northeast and the water level on the southwest, but the belts are not directly superposed. The quantity of oil in each sand is probably determined largely by the richness in oil-forming material of the contiguous shale, and partly by the thickness and purity of the sand.

Development of the field has brought many surprises. It was first thought that the oil sands were anticlinal, and that production would be both east and west of the axis of the surface anticline; but the structure proved to be three terraces on a monocline, and the wells on the reverse dips in Sections 20 and 21 found brown shale instead of sand. It was also thought that accumulation would be on the more gentle dips, but the reverse is true. Wells making 200 barrels offset small wells making 25 barrels, and the explanation appears to be sand condition rather than structure. Salt-water wells and some which missed the oil sands have been drilled along the supposed trace of subsurface cross-faults which are beneath the major surface faults. The small wells in Section 34, where the structure resembles that in Section 28, are explained by a thin and shaly sand. In brief, accumulation depends on the lensing-out of the sands and on the lithology of the sand bodies. Accumulation under similar structural conditions may be expected beneath any homocline where sands in a thick shale section are cut off by progressive overlap on an older eroded surface.

OIL AND GAS

The oil is green by reflected light and amber by transmitted light, and is similar to other Mid-Continent oil of the same grade. The average gravity in Section 20 is 34°; in Section 28, 39°; and in Section 34, 27.8°. The oil in the last two pools is darker than that of the same gravity in Section 20. The gravity of the oil in the fourth and fifth sands is 36°, and the color is lighter. The gravity of the oil in the Ordovician limestone was the same as in the Pennsylvanian sands. Differences in gravity of the oil in the three pools indicate no connection between the sands.

Oil is produced in two wells in Section 17 from the heavy-oil series above the other sands, and the gravity of this black oil varies from 28° to 31°.

TABLE I

ANALYSES OF OIL, CRINERVILLE FIELD

	Oil from "Second" Sand, Sammy Baptiste No. 1, SW.¼, NE.¼, SE.¼, Sec. 20	Oil from Ordovician, Westheimer & Daube Fee No. 1, SW.¼, NW.¼, SW.¼, Sec. 21
API. gravity at 60° F.	33.2	30.7
Saybolt viscosity at 100° F.	58.8	66.0
Percentage of sulphur	0.72	0.83

FRACTIONAL DISTILLATION OF 800 CC. SAMPLE

	Percentage	API. Gravity	Percentage	API. Gravity
Fraction up to 150° C.	12.25	65.6	5.25	60.2
Fraction 150°–200° C.	11.70	53.7	11.50	51.6
Fraction 200°–250° C.	9.70	45.3	12.00	43.4
Fraction 250°–300° C.	11.12	38.8	11.75	38.0
Residue and loss	55.23	....	59.50	....

The casinghead gas carries 1½ to 2½ gallons of gasoline per thousand cubic feet of gas, and the volume of casinghead gas in Section 20 is approximately 1,000 cubic feet per barrel of oil, and only half this amount in Section 28.

Analyses of the oil are given in Table I. It is noticeable that the oil from the Ordovician was low in sulphur, although the accompanying gas was full of sulphur.

Gas has been found in three wells in Pennsylvanian sands and in one well in the Ordovician limestone. The maximum volume of the first wells did not exceed 3,000,000 cubic feet, but one Ordovician well (Marris No. 2) had a volume of 30,000,000 cubic feet of sulphur gas and caused an artesian flow of salt water of 15,000 barrels a day with about 200 barrels of oil. The rock pressure at Farve No. 9 in Section 20 was only 335 pounds at 1,486 feet, instead of a normal pressure of about 500 pounds.

WATER

Water pressure is very low throughout the field, and this is one of the reasons for the small production. There is bottom water in Section 28, and several wells have been plugged back. Edge water has not encroached on the field. Water invariably produces 2–8 per cent of bottom sediment which is treated chemically and settled out.

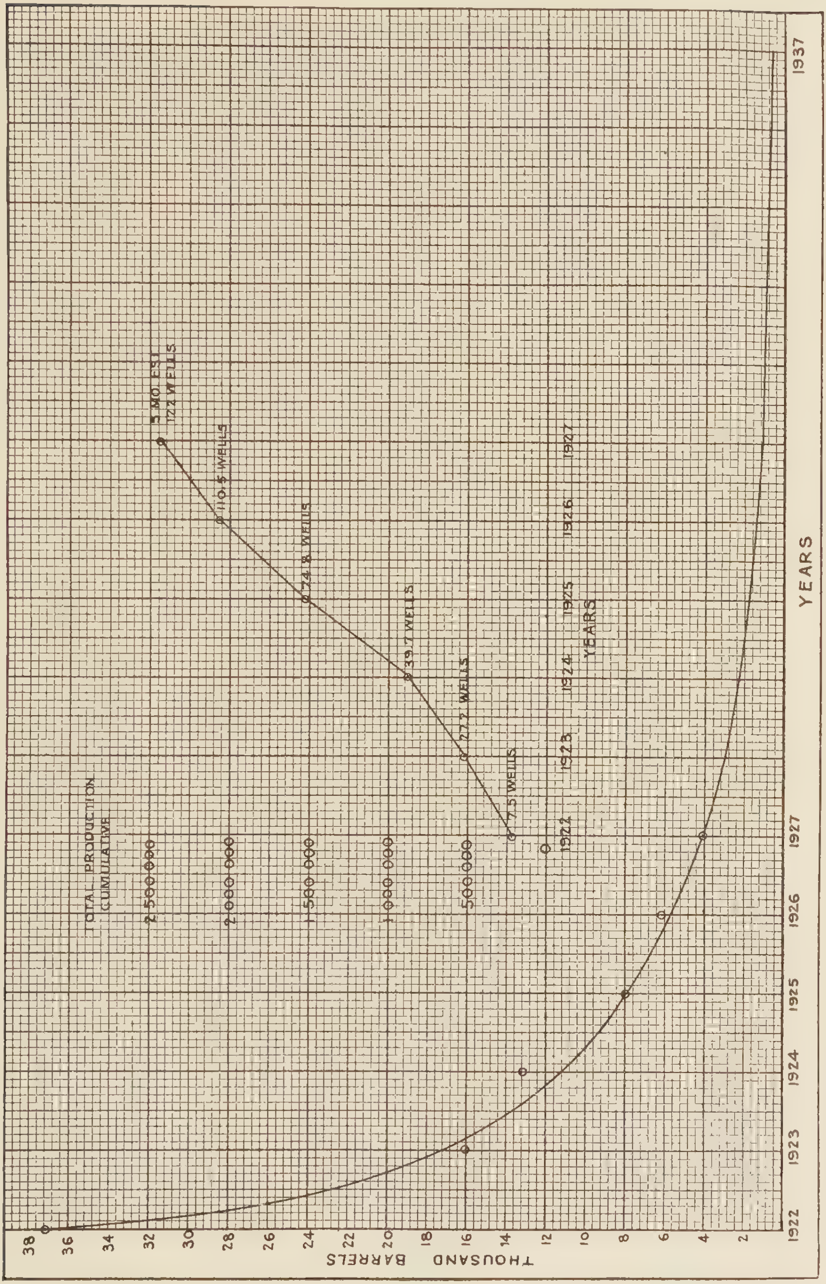


FIG. 6.—Decline curve for the Farve lease of 100 acres in Section 20 and cumulative total production curve for the Crinerville oil field. (By Earle S. Porter, for the Amerada.)

Water pressure was high in the Ordovician limestone and flowed all the oil out of this limited reservoir. Two of the wells flowed 600 barrels of oil a day, but the producing horizon was so closely connected underground that each well affected the others and all went to water eventually, the highest well structurally being the last flooded. After water appeared in a well it increased very rapidly in quantity. Water and gas from the Ordovician have a strong sulphur odor.

Analyses of Ordovician water are given in Table II.

TABLE II

ANALYSES OF ORDOVICIAN WATER, CRINERVILLE FIELD

CONSTITUENT	MARRIS NO. 2, SE. COR. SEC. 20	S. BAPTISTE NO. 4, NE., SE., SE., SEC. 20
	Grams per Liter	Grams per Liter
Calcium chloride	25.380	23.510
Sodium chloride	89.700	85.150
Magnesium chloride	11.818	11.690
Iron and aluminum oxides	0.110	0.120
Silicic acid	0.050	0.090

OIL AND GAS PRODUCTION

All of the wells are drilled with standard tools, and the average time of drilling 1,000 feet is 3 weeks. The spacing is 4 acres to the well.

A decline curve for the Farve lease in Section 20 (Fig. 6) is an average for the field. The productive life of the field will probably be at least 20 years. The maximum production per acre will be 10,000 barrels for the 100 acres of the Farve lease, and 7,000 barrels for the Sammy Baptiste lease south of it. Owing to the fact that there is only one good oil sand in Section 28, the production there will be only 5,000 barrels per acre.

The total ultimate yield of the field will be about 3,300,000 barrels from 560 acres, or 5,900 barrels per acre.

TURKEY MOUNTAIN LIME POOLS, OKLAHOMA[1]

PAUL RUEDEMANN[2] AND H. E. REDMON[3]
Tulsa, Oklahoma

ABSTRACT

The "Turkey Mountain lime" consists of three members: an upper porous, a middle cherty gray, and a lower soft white. The three together average about 60 feet in thickness. Because of the unconformity at the top the whole section is seldom found.

Production from this lime declines rapidly in the initial stage, but generally declines slowly in the settled stage. The ultimate yield is about 8,000 barrels per acre. Production conforms to anticlinal structure and there is no record of synclinal producing wells. The eroded Turkey Mountain surface is undoubtedly the reservoir of many "Wilcox" oil fields. The source of the oil is probably the black and green shales above the "Hominy" sand or the "Turkey Mountain lime" itself.

The producing area from which this horizon derived its name was discovered in 1922 on the south slope of a ridge near Tulsa, Oklahoma, known as Turkey Mountain. As the operators in that pool had no geological departments, no reliable records or complete set of sand samples were kept. Since that time any production found in the same general position with reference to the "Mississippi lime" is referred to as the Turkey Mountain "sand."

The "Turkey Mountain lime" was laid down in late Arbuckle or early Ordovician time. The accompanying table shows its relationship to other horizons below the "Mississippi lime" in northeast and east-central Oklahoma.

The best Turkey Mountain lime pools have been found where the "Wilcox" sand is non-existent. In Wagoner County there are several good gas pools, and farther northwest, in Tulsa and Osage counties, excellent oil pools are found. The most prominent of these are the Turkey Mountain, Country Club, Bruner, Inscho, Oakhurst, Fisher, Bowden, and the new Glidden pool near Sand Springs. All of these pools are within a radius of 60 miles from Tulsa.

Some geologists classify the Hominy production of the southwestern part of Osage County as "Turkey Mountain." This correlation is probably correct. As a rule the pools are not more than 40 acres in extent, and

[1] Read before the Association at the Tulsa meeting, March 26, 1927. Reprinted from *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 9 (September, 1927), pp. 933–44. Revised, October, 1928.

[2] With Ralph E. Davis, engineer, Tulsa Trust Building.

[3] Thompson & Black, Inc., Atlas Life Building.

the bulk of the production is obtained from one or two wells. The initial production from the largest wells may be as much as 7,000 barrels a day, but it declines rapidly, and may continue to do so until water appears. On the other hand, the wells may remain at the small pumper stage for several years. There is considerable variation between pools in the rate of decline after the initial stage is past. The ultimate production averages about 8,000 barrels an acre.

The horizon referred to as Turkey Mountain "sand" is a lime body found in its full extent to be about 100 feet thick. It is not a siliceous, but a dolomitic, lime. Luther White in his publication[1] on the post-"Wilcox" formation of northeastern Oklahoma has mentioned this distinction. Rudolf Ruedemann[2] places this lime as late Beekmantown or Chazy Low-

TABLE I*

Oil-Field Name	Formation Equivalent		Age
"Mississippi lime"........	Mississippian limestone		Mississippian
Black shale..............	Chattanooga shale		
			Unconformity
"Wilcox" sand...........			Middle or Lower Ordovician
Green series or "Irish" sand	Tyner	Simpson	
"Hominy" or "Glass" sand	Burgen (St. Peter)		
			Unconformity
"Turkey Mountain lime".	Arbuckle limestone		Cambro-Ordovician
"Stray sand" (lenticular) .			
"Siliceous lime".........			

* From Luther White, *Oklahoma Geol. Survey Bull. 40-B*, with revisions by the authors.

ville (Ordovician) in age. How far this lime body extends has not been determined but it might at one time have been comparable with other major limestone formations in Oklahoma. The largest production generally occurs where the upper gray porous lime exists. This porous lime is easily recognized from drill cuttings, as it drills into small oval pieces resembling wheat and is stained brown where oil is present. This upper section is sometimes spoken of as the "brown lime." Underneath it lies a gray and in places cherty lime. In places this becomes slightly shaly or sandy and may carry oil. Below the gray lime occurs a white lime series which is very soft and might easily be taken for the Viola limestone. The cuttings from this lime resemble corn flakes. At the bottom of the "White lime" is found a thin lenticular sand, below which is the "Siliceous lime." This thin sand body carries water, and at one location carried a good showing

[1] "Subsurface Distribution and Correlation of the Pre-Chattanooga Series of Northeastern Oklahoma," *Oklahoma Geol. Survey Bull. 40-B* (1926), p. 12.

[2] Personal communication.

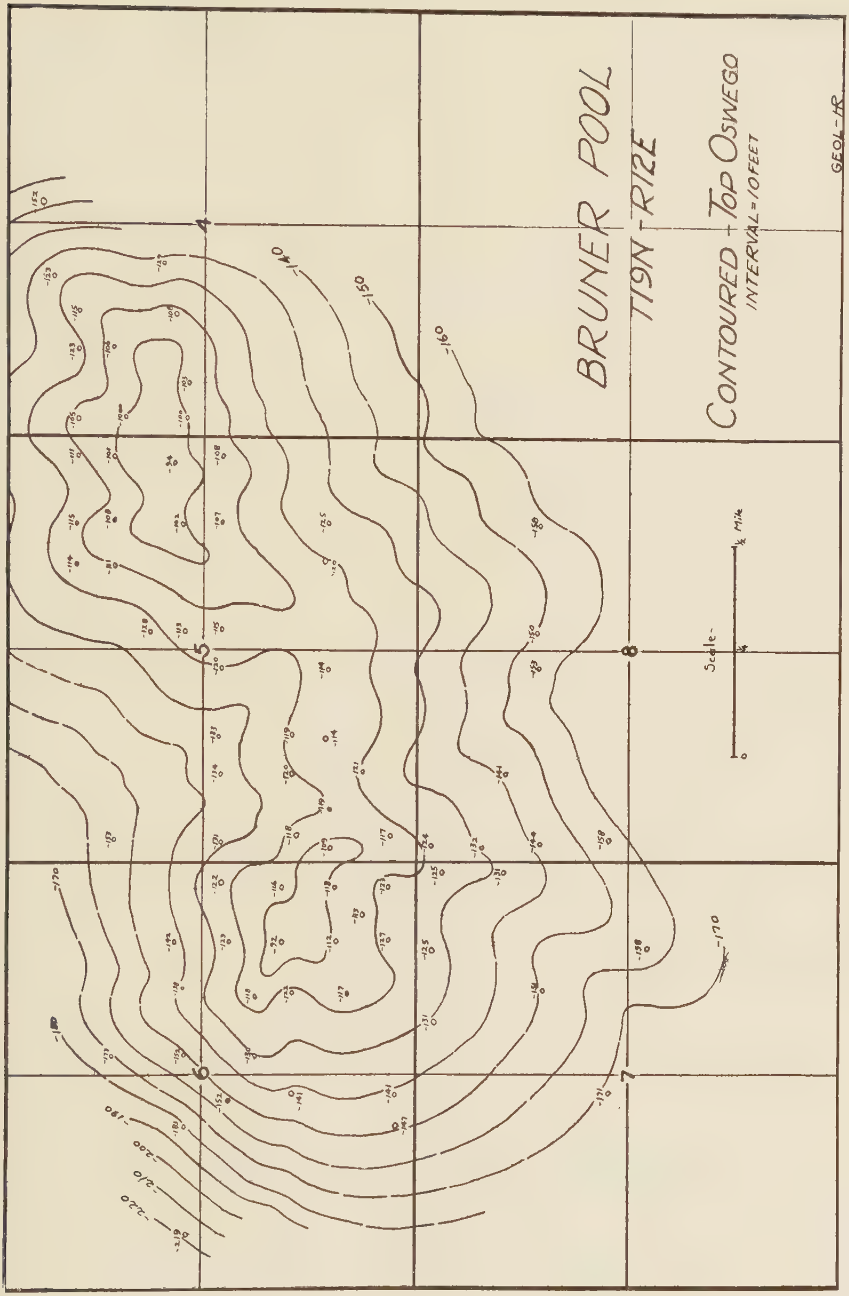


FIG. 1.—Bruner Pool, contoured on the top of the Oswego lime.

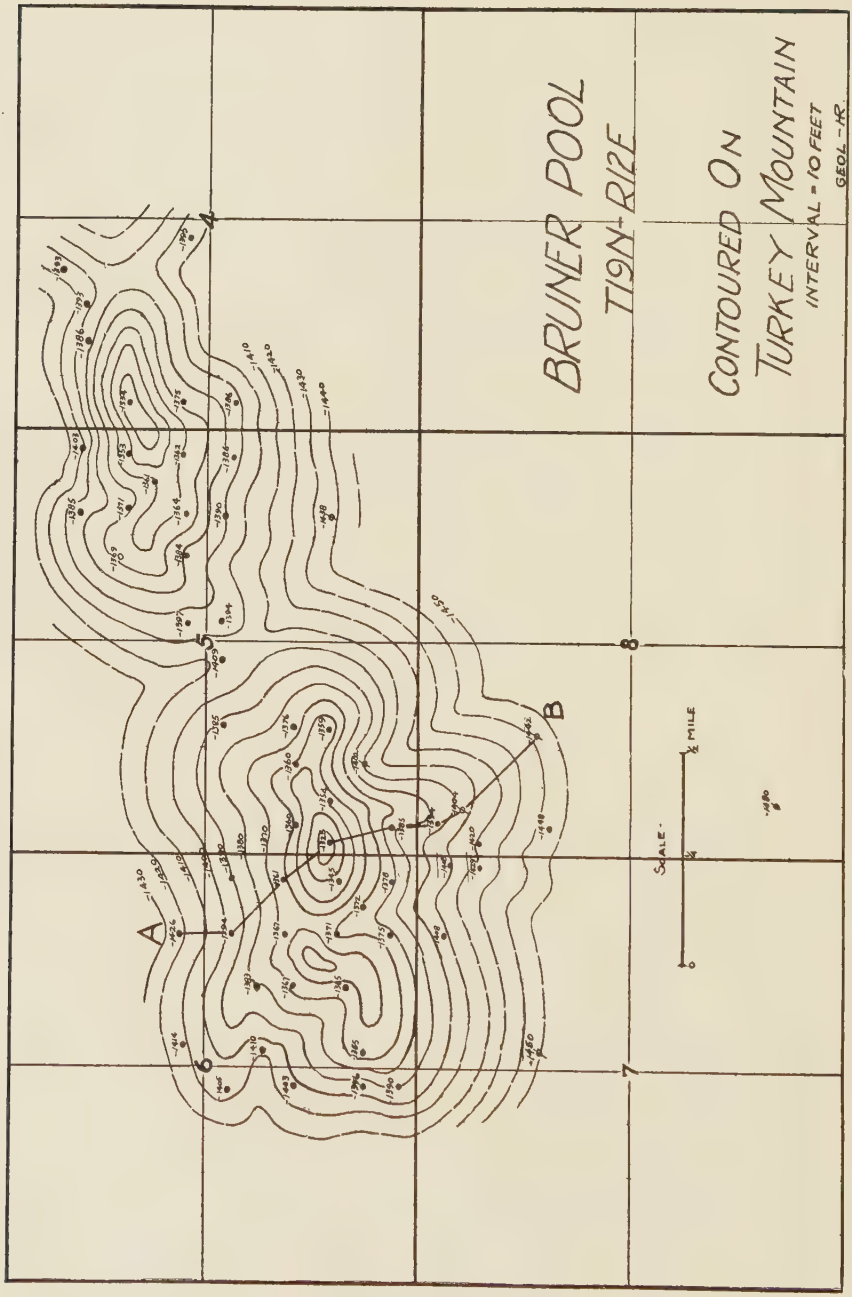


FIG. 2.—Bruner pool, contoured on the top of the "Turkey Mountain lime."

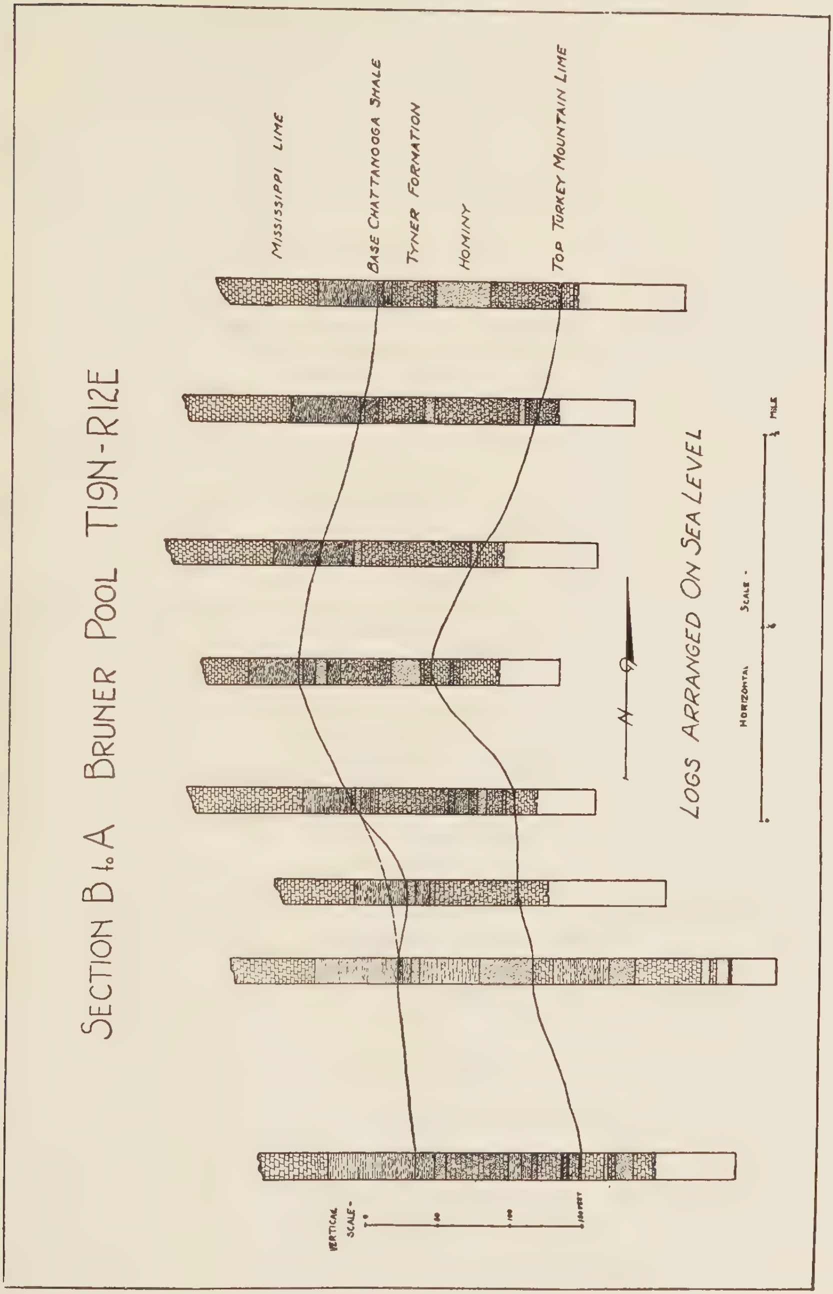


FIG. 3.—Section showing thinning of interval on the apex of the anticline.

of live oil, but the test in this case was not favorably located on structure. Commercial pools may sometime be developed in this horizon. Some bodies, seemingly sand, found throughout the Turkey Mountain limestones are in reality pure calcite, which drills up much like sandstone.

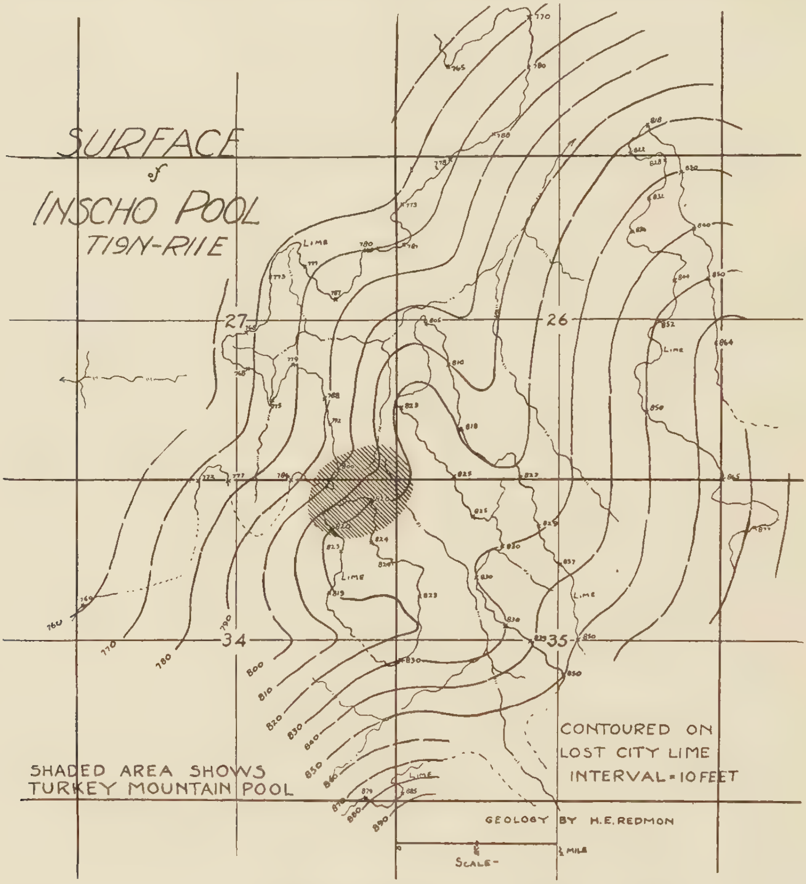


FIG. 4.—Inscho pool, showing the relation of the Turkey Mountain pool to the surface terrace.

An interval of 200 feet below the base of the "Wilcox," if present, and otherwise the base of the Chattanooga, will in most places reach the Turkey Mountain.

The top of the "Turkey Mountain lime" is an unconformable surface. The unconformity occurs between it and the later formations, but it is apparently conformable with the "Siliceous lime." This accounts for the

irregularity of the production, and in places the presence of gushers on the flanks and small producers or dry holes on the tops of the anticlines. It also accounts for the complete or partial absence of the lime in many places. Contrary to what one would expect, this lime seems to be thicker on the anticlines than in the synclines, but this tendency cannot be proved on the present meager information.

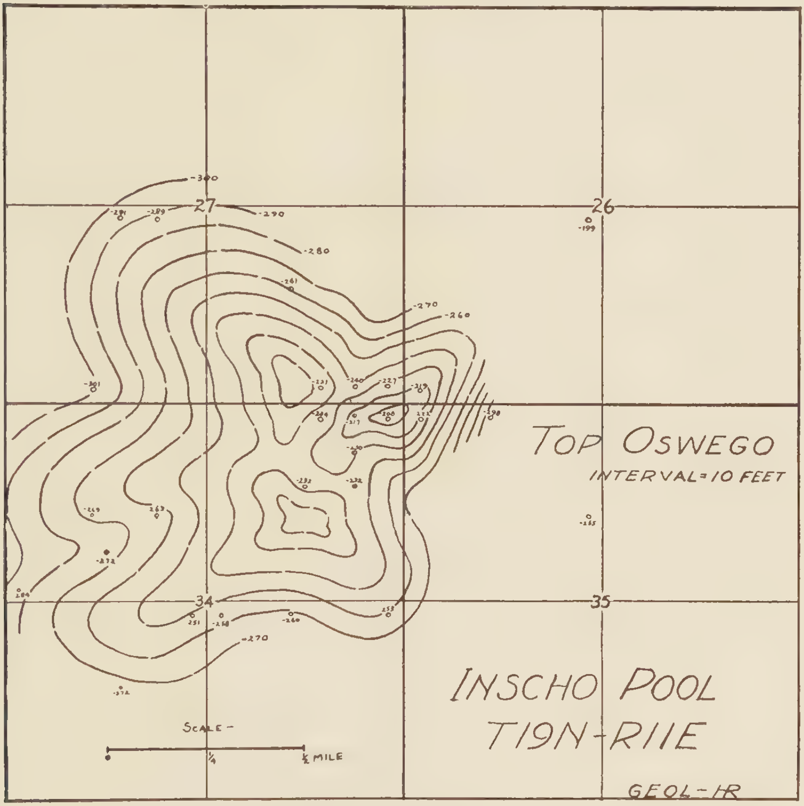


FIG. 5.—Inscho pool, contoured on the top of the Oswego lime.

The Bruner pool in T. 19 N., R. 12 E., 6 miles west of Tulsa on the Sand Springs road, and the Inscho pool in T. 19 N., R. 11 E., are herein described as type pools. In the Bruner pool there is a closed anticline on the Oswego lime. There being little or no "Wilcox" sand present, the bottom of the Chattanooga shale is used as the next marker. The apex of the anticline in this horizon is about one-quarter mile southeast and the rate of dip is about twice that of the Oswego structure. The contours on top of the

"Turkey Mountain lime" show the apex in the same relative position as found at the bottom of the Chattanooga shale, but the dip has three times the rate of that found in the Oswego structure. This indicates considerable thinning of interval on the top of the structure between the Chattanooga shale and the top of the "Turkey Mountain lime," due to erosion and compaction.

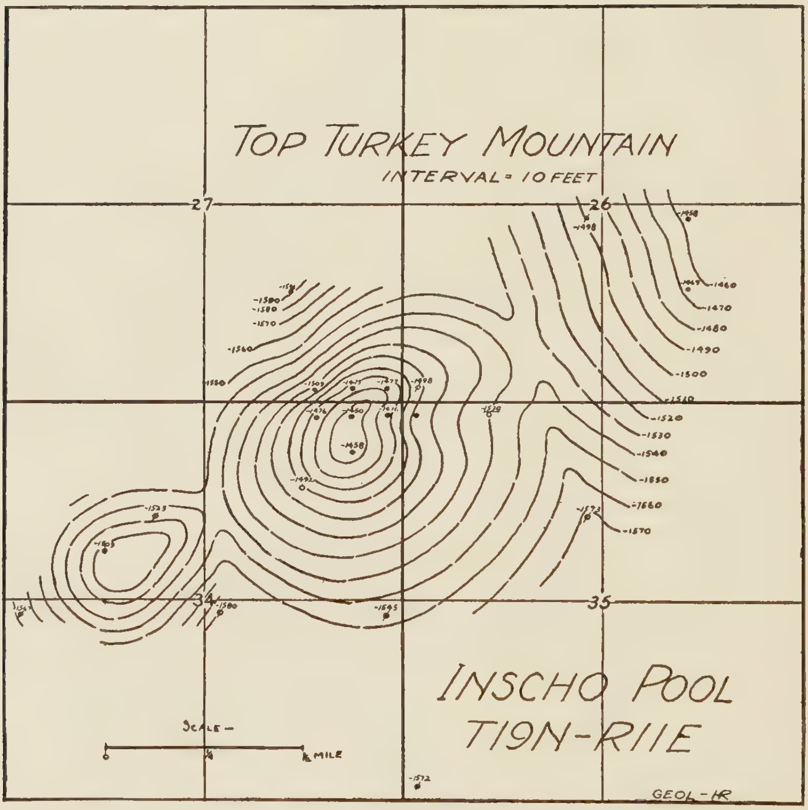


FIG. 6.—Inscho pool, contoured on the top of the "Turkey Mountain lime."

Because of the erosion of the "Turkey Mountain lime," the true top of the original Bruner anticline may have been one-quarter mile farther south than the present dome shows. In this pool the wells on the north flank found the porous lime which is the upper member of the "Turkey Mountain lime" series; whereas, the wells on the south flank passed from the "Hominy" sand into the gray lime member below the porous lime.

In the Inscho pool the "Turkey Mountain lime" fold is centered under the Oswego high, and the dip, as in the Bruner pool, has trebled in rate in the deeper formation.

In Turkey Mountain pools, in general, the best production seems to occur where the porous lime member is present. This is not everywhere essential. The original Turkey Mountain pool itself is producing from the gray lime member, according to supposedly reliable drill cuttings. In a small pool about 6 miles east of the original Turkey Mountain field, the porous and gray lime members are both absent and production on top of this dome was found in the lower part of the "White lime" member, although a test less than a quarter-mile southwest found no part of the "Turkey Mountain lime" series. Near Haskell a gas pool occurs in the white series. If any of the lime members are sufficiently porous, commercial production is likely to be found, even though the main part of this series might have been eroded. Turkey Mountain production exists only on closed anticlines, but only a few such structures contain commercial production. Water of commercial value occurs in this formation. The radium water springs of the Claremore district are Turkey Mountain. The Sand Springs Home saves all the salt water from the Bruner pool and has built up a profitable industry for the extraction of salts.

As stated previously the "Turkey Mountain lime" pools to date have been found only where productive "Wilcox" sand does not exist. This may be a coincidence, as in the areas where "Wilcox" sand is productive there are not enough tests favorably located to eliminate the "Turkey Mountain lime" as a potential producing horizon under existing "Wilcox" pools. "Turkey Mountain lime" production probably covers a far greater area than we now anticipate. The source of the oil found in the "Wilcox" sand is generally conceded to be the Chattanooga black shale. It is difficult to conceive of this black shale as being the source bed of Turkey Mountain production, especially where sand bodies capable of making an oil reservoir are found between it and the black shale. It might be assumed that the oil traveled downward through faults or that the oil migrated along the "Turkey Mountain lime" contact from the areas where the black shale lies against the Turkey Mountain formations. This seems improbable, and it is more likely that the source of the oil is in the black and green shales commonly found above the "Hominy" sand, or from the "Turkey Mountain lime" itself.

BURBANK FIELD, OSAGE COUNTY, OKLAHOMA[1]

J. MELVILLE SANDS[2]
Bartlesville, Oklahoma

ABSTRACT

Local structural conditions seem to have had little influence on the concentration of oil in this field. The area is an undulating monocline with a general westward dip of about 35 feet to the mile. On the north and east sides of the field the oil-bearing sand grades in a short distance into an impervious shale, and this impervious shale prevents the oil from traveling farther up the dip. On the west and lower side of the field the oil is in contact with salt water. The oil production from each well also seems to be in proportion to the porosity of the sand in the immediate vicinity of the well, and has little if any relation to rock deformation. The shale barrier north and east of the field, therefore, has been the medium which retained the oil in its present position, and the porosity of the reservoir rock in the vicinity of each well has regulated that well's daily and ultimate production.

INTRODUCTION

The purpose of the writer is to discuss the following phenomena of the Burbank field: (1) the influence of structure on petroleum accumulation and concentration; (2) the relation between the porosity of the reservoir rock and its oil content and production.

HISTORY

The first oil produced in Osage County was on its eastern line, near Bartlesville, Oklahoma, and from the Bartlesville sand. This was found at a depth of 1,600 feet, near the base of the Pennsylvanian series. It is the most widespread and prolific of any oil sand in the county. The western limit of this sand, as now known, may be shown by a northeast-southwest line nearly through the center of the county. Because developments started in the eastern part of the county and worked west, operators, after drilling many dry holes west of the center of the county, became reluctant to drill even on well-known anticlines in the western Osage, in which the Burbank field is located. It was not until the Marland Oil Company drilled in its first well in the Burbank field in May, 1920, in the SE. $\frac{1}{4}$ of Sec. 36, T. 27 N., R. 5 E., and the Carter Oil Company drilled in its first well in September, 1920, in Sec. 9, T. 26 N., R. 6 E., on

[1] Presented by title before the Association at the Tulsa meeting, March 26, 1927. Manuscript received by the editor, May 13, 1927. Reprinted from *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 11 (October, 1927), pp. 1045–54.

[2] Consulting geologist, Phillips Petroleum Company.

two small anticlines, that the possibilities of the Burbank field were recognized by oil men in general. Since that time, thirteen sales of oil leases have been held by the Osage agency under the direction of the United States Government. At these sales, quarter-sections are auctioned to the highest bidder. So far the highest price paid has been $1,990,000 for the 160 acres in the NE. $\frac{1}{4}$ of Sec. 14, T. 27 N., R. 5 E., which was bought by the Midland Oil Company. Including the small part of the field which is in Kay County, 170 quarter-sections are producing. More than 130,000,000 barrels of oil have been extracted from the field. The production at present is 43,000 barrels daily from 2,000 wells. With one well to ten acres, the recovery to date averages 6,500 barrels per acre, while some leases have produced 20,000 barrels per acre. Figure 1 shows the production-decline curve of this field, the average production per well per day, and the average number of wells producing, from 1921 to 1927.

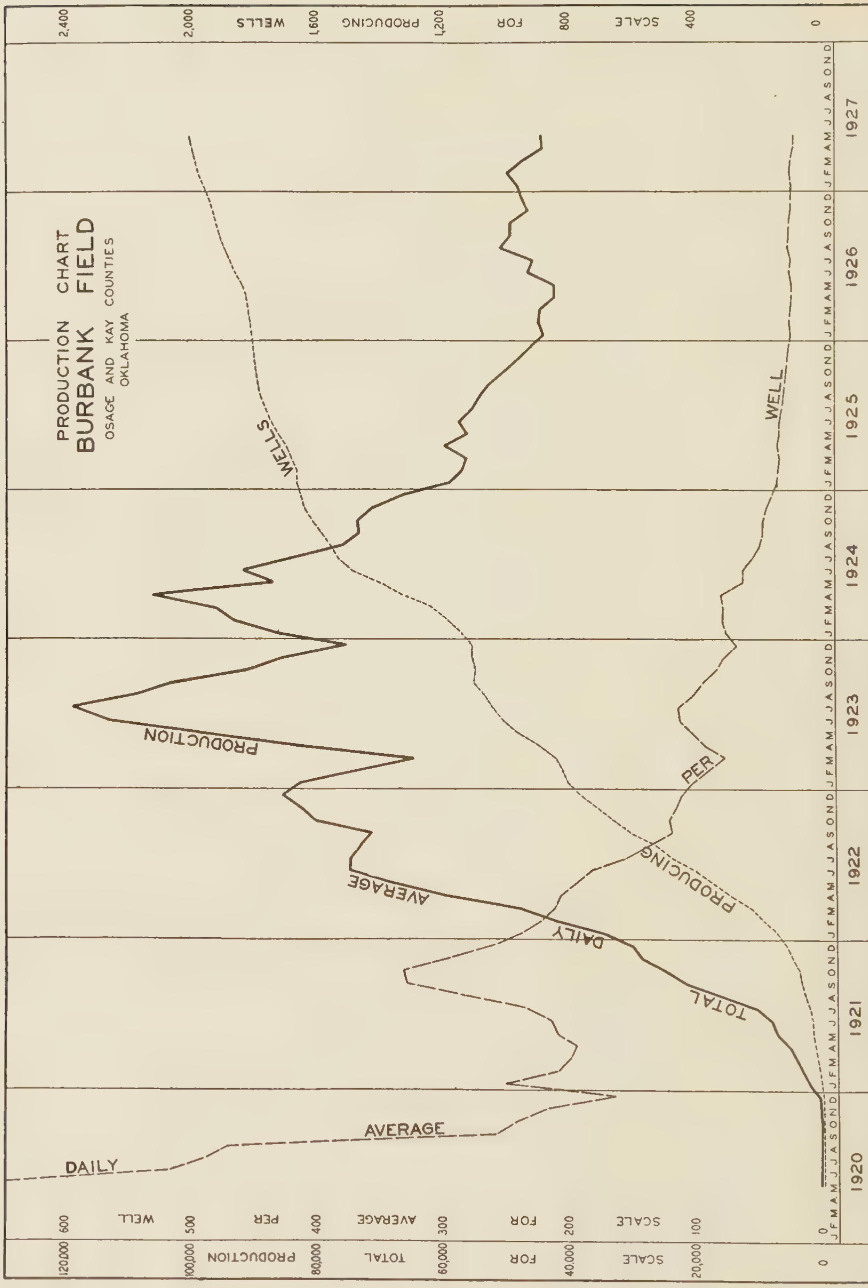
STRATIGRAPHY

The stratigraphy of Osage County has been so thoroughly studied by all of the oil companies operating in that district, and also has been described so completely in several publications,[1] particularly those of the United States Geological Survey[2] and the Oklahoma Geological Survey,[3] that space will not be taken here to describe the different members in detail. The surface rocks of the entire county, with the exception of a small area in the northwest part, are of Pennsylvanian age; Permian rocks overlie the Pennsylvanian conformably in that area. The contact of the Permian and Pennsylvanian extends northeast and southwest, through the eastern side of the Burbank field, so that most of the limestones used in working the surface structure are of Permian age. The total thickness of the Pennsylvanian series in Osage County is about 2,900 feet. It contains several different producing horizons in different parts of the county, some fields producing from several horizons at the same time. The Burbank field, however, is producing commercially only from the Burbank sand, which is near the base of the Pennsylvanian series at a depth of 2,800 feet in the southeastern part of the field, and a depth of 3,200 feet in the northwestern portion. It is a fine-grained, siliceous sand, having a calcareous cementing material. Its thickness ranges from 50 to 80 feet. Melcher's examination[4] shows the pore space to range from 13.7 per cent

[1] J. M. Sands, "Burbank Field, Osage County, Oklahoma," *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 8, No. 5 (1924), pp. 584–92.

[2] *U. S. Geol. Survey Bull. 686.* [3] *Oklahoma Geol. Survey Bull. 19.*

[4] "Texture of Oil Sands with Relation to the Production of Oil," *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 8 (1924), pp. 716–74.


PRODUCTION CHART
BURBANK FIELD
OSAGE AND KAY COUNTIES
OKLAHOMA
PRODUCING WELLS
TOTAL PRODUCTION
DAILY AVERAGE PER WELL
SCALE FOR PRODUCING WELLS
SCALE FOR TOTAL PRODUCTION
SCALE FOR AVERAGE PER WELL
1920
1921
1922
1923
1924
1925
1926
1927

to 32.7 per cent by volume. The thickness of the sand is not uniform, and in some places there is a stratum of blue shale ranging from a few inches to 3 feet in thickness at about 50 feet from the base of the sand. Where the sand is thickest, about 80 feet, the sand above this blue shale is about 30 feet thick and carries nothing but gas. It is quite probable that the range in the thickness of the Burbank sand is caused altogether by the range in thickness of this upper member, and that, where the oil is found at the surface of the sand, this upper member is very thin, or in some places entirely absent. Though the lower 50 feet of the sand is generally a pure sand without any shale breaks, its porosity and content of calcareous material differ, so that the sand is probably not productive throughout its total thickness. The production comes from three or four different zones encountered at different depths, and it is quite probable that not more than two-thirds of the total thickness is productive.

Stratigraphically, the Bartlesville and the Burbank sands in Osage County, Oklahoma, and the Rainbow Bend and Fox Bush sands in Kansas, seem to be at about the same horizon. The Bartlesville sand, however, is a blanket formation covering a large part of northeastern Oklahoma and a small part of southeastern Kansas, while the other three sands mentioned have much smaller areas and may be in the form of large lenses. In the vicinity of the Burbank field, the Burbank sand has been encountered as a water sand considerably outside the field in several localities, and within the last year the Kewanee pool, 1 mile east of Burbank production, and the Fairfax pool, located 6 miles south of the Burbank pool, have developed production in this sand. Whether or not these two pools ultimately will be found to connect with the Burbank field and whether or not the sand of the Fairfax pool will be found to continue south to connect with the Bartlesville sand, will remain for further development to discover. There is a distance, however, of 18 miles between the western edge of the Bartlesville sand near Pawhuska and the eastern edge of the Burbank sand in that field proper.

The Burbank sand is separated from the "Mississippi lime" below by 40–70 feet of blue Cherokee shales. The "Mississippi lime" here is a series of hard, semicrystalline, blue limestone beds, divided by more shaly or chalky, softer members. The total thickness is 320 feet. Beneath this is 130 feet of black Chattanooga shales, beneath which is the "Wilcox" sand. In this field, this sand is rather fine-grained and calcareous, but is sufficiently porous to have a showing of oil and a hole full of water. This oil was encountered in the Carter well in Sec. 9, T. 26 N., R. 6 E., which is located in the highest part of the field. This well should have been a

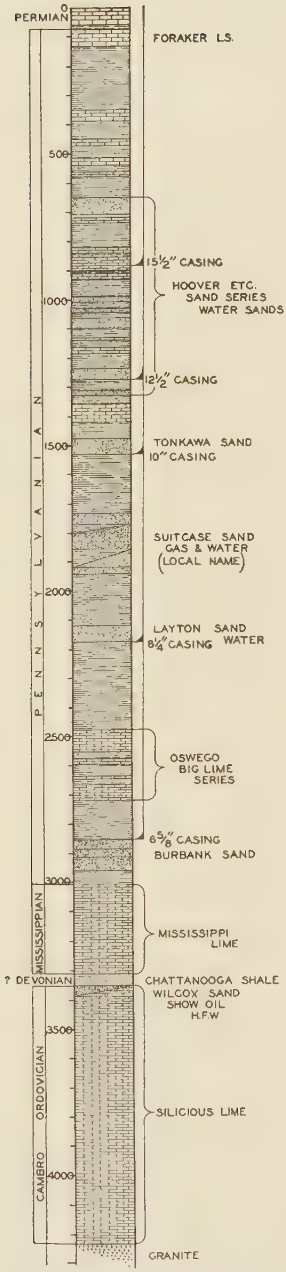


FIG. 2.—Type log, Burbank field, Osage and Kay counties, Oklahoma. Depths in feet.

splendid test for production in this sand. It is therefore improbable that any "Wilcox" production will be found in this field, although, because of the existence of this sand in this district and the showing of oil in it, there is very good reason to suppose that in districts in this vicinity where conditions have been more favorable for oil depositions in this sand, there should be production developed in it. Beneath the "Wilcox" sand is 860 feet of "Siliceous lime." This lime is composed of thick, cherty members of hard gray siliceous limestone interbedded with thinner members of a more shaly or sandy nature. No oil or gas was encountered in it. Below the siliceous limestone is granite. This granite is in much the same class as that found in the granite ridge extending through Kansas and the northwest corner of Osage County. The granite was encountered in only one well in the field, that being the well of the Carter Oil Company located in the northwest corner of the NW. $\frac{1}{4}$ of Sec. 9, T. 26 N., R. 6 E. The granite was encountered at 4,240 feet. A type well log of the field is shown in Figure 2. The lower 700 feet is taken from the Carter Oil Company's well.

STRUCTURAL CONDITIONS

The Burbank field is included in the territory situated on the western flank of the great regional uplift which has for a center the Ozark Plateau. This west flank includes northwestern Arkansas, northeastern Oklahoma, southeastern Kansas, and southwestern Missouri. The strata in Osage County dip a little north of west at the rate of about 30 feet to the mile, this dip being changed and reversed in different localities, according to local structure conditions.

Figure 3 shows surface structural conditions in the Burbank field, using the Stone-

breaker limestone as datum. The general dip is about 35 feet to the mile, approximately due west. The only reversals developed are a small dome with about 20 feet of closure in Sec. 9, T. 26 N., R. 6 E. and a still smaller dome with 10 feet of closure at the intersection of T. 26-27 N. and R. 5–6 E., the latter being 100 feet lower than the former.

Figure 4 shows structural conditions developed on top of the Burbank sand. A comparison of these two figures shows a much greater deformation of the subsurface structure than of the surface. There are several small domes and synclines, and the two small domes shown on the surface have had their closure greatly increased. The one in Sec. 9, T. 26 N., R. 6 E. shows 50 feet of closure, while in the one at the intersection of T. 26–27 N., and R. 5–6 E. there are 35 feet of closure.

The structural conditions of the Burbank field may then be called an undulating monocline dipping at the rate of about 35 feet to the mile in a westerly direction, with the largest deformation being the previously mentioned anticlines which are at the southeast end of the field. This monoclinal condition, deformed by small reversals, is general throughout the territory.

OIL CONCENTRATION

As far as it has been possible to determine, structural conditions have only a secondary and minor influence in the concentration of oil in this field. The oil sand saturation and the production of wells therefrom seems to be in proportion to the porosity of this sand.

Melcher states:[1]

> The production-porosity curve of the Burbank field shows evidence not only of an interesting relation between the average percentage of pore space of the producing sand and the greatest production for 24 hours of the wells, but also indicates that in the Burbank field the greatest rate of production will be in areas of largest average percentage of pore space, regardless of relation to geologic structures. The curve indicates also that an average pore space of about 13 per cent is the lower limit for commercial production of the producing sand in the Burbank field.
>
> The close relation between average percentage of pore space and maximum production for 24 hours of the wells is largely due to the small ranges of variations in most of the other physical factors, as structure, size of grain, pressure and temperature, specific gravity, and viscosity of the oil.

The highest points structurally in the field are among the places of smallest oil production, and, while more than the ordinary amount of gas is found with the oil at these places, yet they are not even the most productive portions of the field for gas production. The most prolific portions of

[1] "Texture of Oil Sands with Relation to the Production of Oil," *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 8 (1924), pp. 716–74.

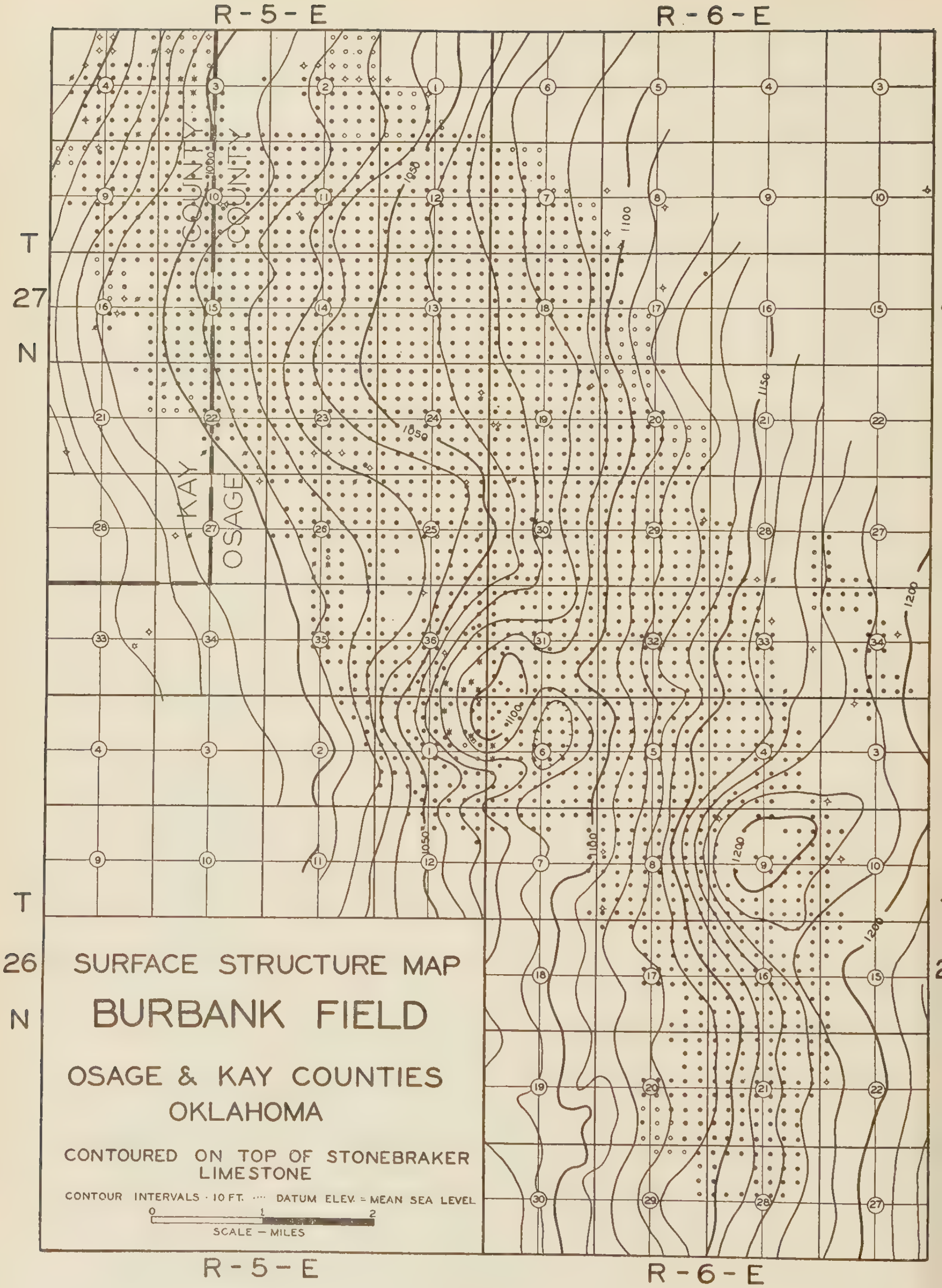

R-5-E
R-6-E
T
27
N
T
26
N
KAY COUNTY
OSAGE COUNTY
KAY
OSAGE
1000
1050
1100
1150
1200
SURFACE STRUCTURE MAP
BURBANK FIELD
OSAGE & KAY COUNTIES
OKLAHOMA
CONTOURED ON TOP OF STONEBRAKER LIMESTONE
CONTOUR INTERVALS · 10 FT. ···· DATUM ELEV. = MEAN SEA LEVEL
0 1 2
SCALE — MILES
R-5-E
R-6-E

FIG. 3

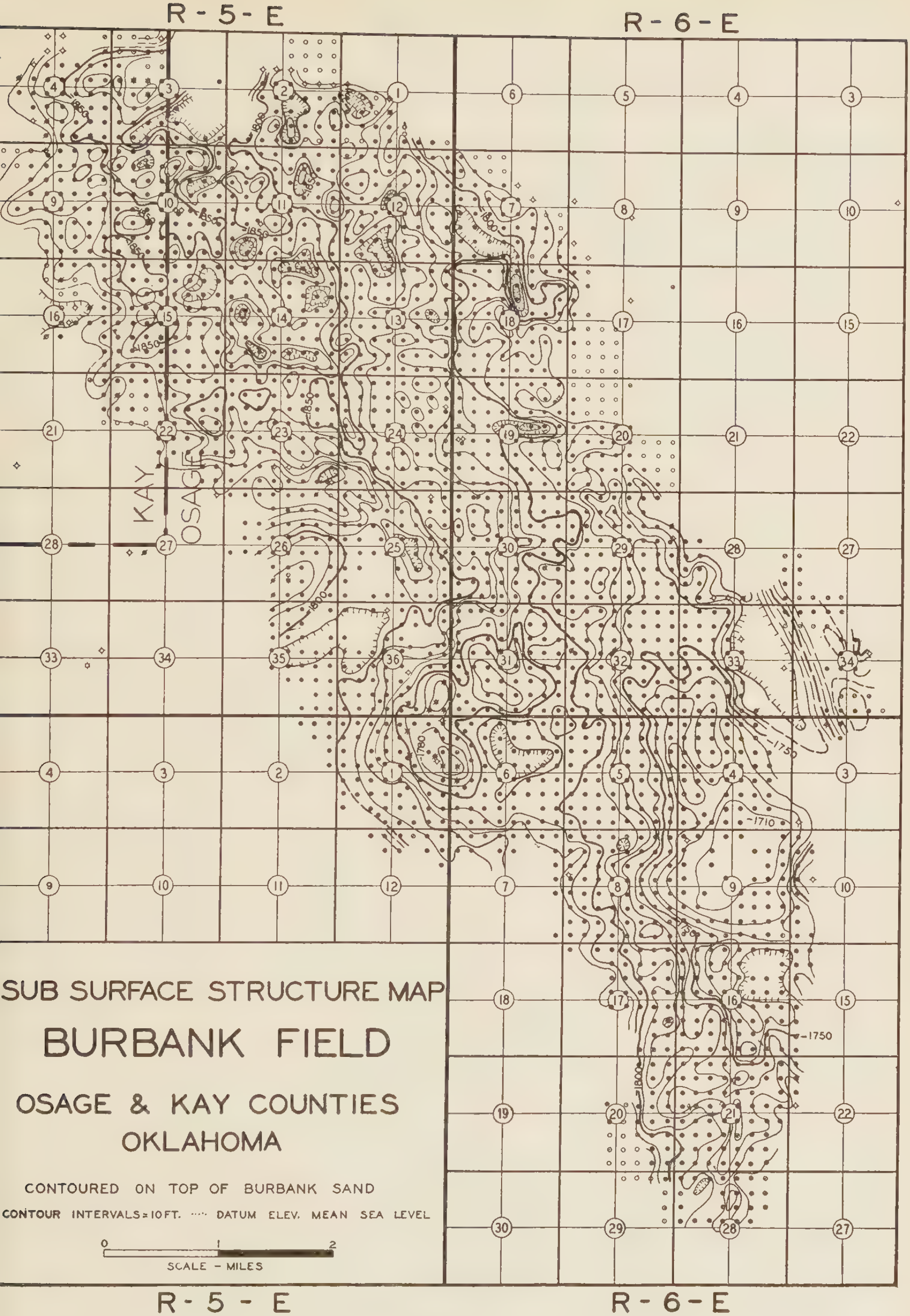

R-5-E
R-6-E
KAY
OSAGE
SUB SURFACE STRUCTURE MAP
BURBANK FIELD
OSAGE & KAY COUNTIES
OKLAHOMA
CONTOURED ON TOP OF BURBANK SAND
CONTOUR INTERVALS = 10 FT. ···· DATUM ELEV. MEAN SEA LEVEL
SCALE – MILES
R-5-E
R-6-E

FIG. 4

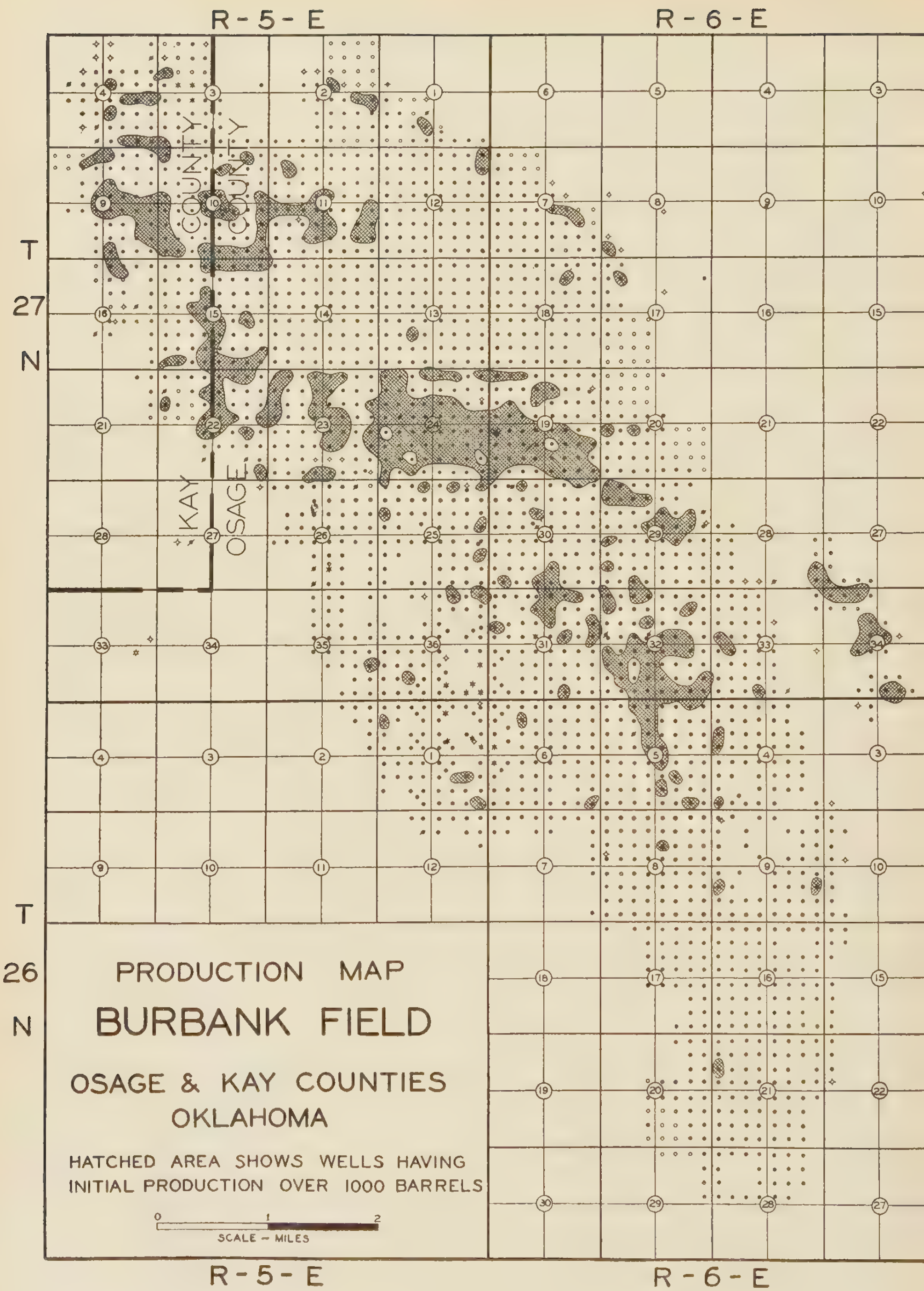

R-5-E
R-6-E
T
27
N
T
26
N
KAY COUNTY
OSAGE COUNTY
PRODUCTION MAP
BURBANK FIELD
OSAGE & KAY COUNTIES
OKLAHOMA
HATCHED AREA SHOWS WELLS HAVING
INITIAL PRODUCTION OVER 1000 BARRELS
0
1
2
SCALE – MILES
R-5-E
R-6-E

FIG. 5

the field for oil production are in the northwest part, several miles from the highest point structurally, and from 100 to 150 feet below it. The production of the wells changes in a few hundred feet from that of a very large well to a comparatively small one, depending on the porosity of the sand in the two wells. The most porous portions of the sand seem to be in irregular patches, mostly disconnected and in fairly small units, scattered through the whole field, but of large size and more numerous in the northwest portion. This is shown in Figure 5.

On the northern and eastern sides of this field the producing sand grades abruptly into an impervious sandy shale. This change of lithological character has been the primary reason for oil concentration, oil and gas having traveled up the slope in an easterly direction until they could go no farther. Some gas separated from the oil into portions of the reservoir rock, which was not porous enough to admit the oil, this concentration of gas being particularly noticeable on the tops of the two main structures and in places on top of the producing horizon where it had become thickened on top with a fine-grained, almost impervious sand member. Gas also was present in large quantities in the extreme northern end of the field, which is the lowest part of it, the gas being found structurally below the oil where the producing sand was so fine-grained that the oil or water could not penetrate it, but where the pore space was sufficient to allow the gas to accumulate.

Another peculiar feature of this field, besides the irregularly spaced and shaped porous portions of the producing sand scattered throughout the field, is a very porous and productive zone strung along the northeastern extremity of the field. This zone is not more than a quarter of a mile wide and grades in a very short distance into the impervious shale which limits the area of the field in that direction. The writer is not conversant enough with all of the theories of deposition, sedimentation, and cementation of rocks to be sure of the cause of this porosity, but believes that it is probably caused by the leaching of the calcareous cementing material after deposition by a current of water directed in this course by the impervious nature of the rock on the northeast, and that after this leaching the pore space was filled with oil.

To sum up, it seems that oil and gas have been trapped in the Burbank field because they could not travel any farther east, and that in so accumulating they were concentrated in the most porous portions of the reservoir rocks. Therefore, the controlling factors in the oil concentration were the impervious barrier on the eastern side of the field and the porosity of the reservoir rock in the field, and not the structural conditions.

GEOLOGY OF GLENN POOL OF OKLAHOMA[1]

W. B. WILSON[2]
Tulsa, Oklahoma

ABSTRACT

Glenn pool was the first major oil pool to be developed in Oklahoma. Opened in 1906, it has long since been fully developed in the Bartlesville (Glenn) sand of Cherokee age which has been by far the main producing horizon. Local doming is present and has caused unimportant accumulations in the Mounds ("Wilcox") sand. Accumulation in the Bartlesville, however, is not related to local folding, but is due to the pinching out of the sand body on the eastern or up-dip side of the field.

The writer believes that this pool furnishes very conclusive evidence that its oil was trapped while in transit up the dip from the west. He holds also that the most satisfactory explanation yet advanced for this movement of the oil up the dip is buoyancy arising from the difference in specific gravity between the oil and the associated waters.

INTRODUCTION

Glenn pool was the first of Oklahoma's major oil fields. The fields in Oklahoma that at some time have had a production peak in excess of 100,000 barrels daily are, in the order of their discovery, Glenn, Cushing, Healdton, Burbank, Tonkawa, and Seminole.

In 1914 Carl D. Smith[3] briefly described the stratigraphy of Glenn pool and published a generalized subsurface structure map of the pool and vicinity on the datum of the top of the Fort Scott (Oswego) limestone. Information now available permits revision and correction of this early paper. The writer wishes here to express his appreciation to the members of the geological staff of the Gypsy Oil Company, and especially to Miss Constance Eirich, for helpful suggestions on the subject matter of this paper and in the preparation of the maps and sections with which it is illustrated.

LOCATION

The main producing area of Glenn pool is located in the northwest part of T. 17 N., R. 12 E., Creek County, Oklahoma. A portion of the pool,

[1] Read before the Association at the Tulsa meeting, March 24, 1927. Manuscript received by the editor, August 2, 1927. Reprinted from *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 10 (October, 1927), pp. 1055–65.

[2] Gypsy Oil Company.

[3] Carl D. Smith, "The Glenn Oil and Gas Pool and Vicinity," *U. S. Geol. Survey Bull. 541* (1914), pp. 34–39.

with relatively low productivity, extends into the southwest part of T. 18 N., R. 12 E., and is commonly designated the North Extension. At one time this area was the center of much drilling activity, but development has now moved westward and at present little consideration is being given to territory east of the field.

HISTORY

The discovery well in the pool was drilled by Galbreath and Chessley on the Ida Glenn farm near the center of the SE. $\frac{1}{4}$ of Sec. 10, T. 17 N., R. 12 E., in December, 1906. Its initial production was 75 barrels daily from a sand encountered at approximately 1,475 feet, designated then as the Glenn sand and later correlated with the Bartlesville. The writer has been unable to verify a report that a seepage or showing of oil at the surface influenced the selection of the location. Presumably the site for the test was chosen without knowledge of local geological conditions, and if a location less than one-half mile farther east had been selected a dry hole would have resulted.

The producing area was extended rapidly westward and northward and a production peak of about 120,000 barrels daily was reached in the autumn of 1907, much of the oil, however, being run to storage. The peak of marketed production was reached in 1908 at approximately 80,000 barrels daily. The present production is nearly 10,500 barrels daily from approximately 4,000 wells. The recovery per acre has varied widely in the field. A few leases have produced to date in excess of 40,000 barrels per acre, but the average for the pool is less than one-fourth that amount.

Long since completely drilled to its principal producing sand, the field is now of interest chiefly in a historical and scientific way. However, the writer believes that only a minor fraction of the original oil content has been removed by production methods of the past and present, and that the pool is especially well adapted for additional recovery by the application of pressure or flooding methods. On this account the pool may some day stage a comeback that will contribute an item of importance to production statistics.

STRATIGRAPHY

PENNSYLVANIAN

In Figure 1 is shown a generalized columnar section for the Glenn pool area. Pennsylvanian rocks are at the surface and beds of that age extend downward to a depth of approximately 2,000 feet. Subdivisions of this part of the section are not based on an intensive and systematic study of well cuttings, but represent merely the commonly accepted termi-

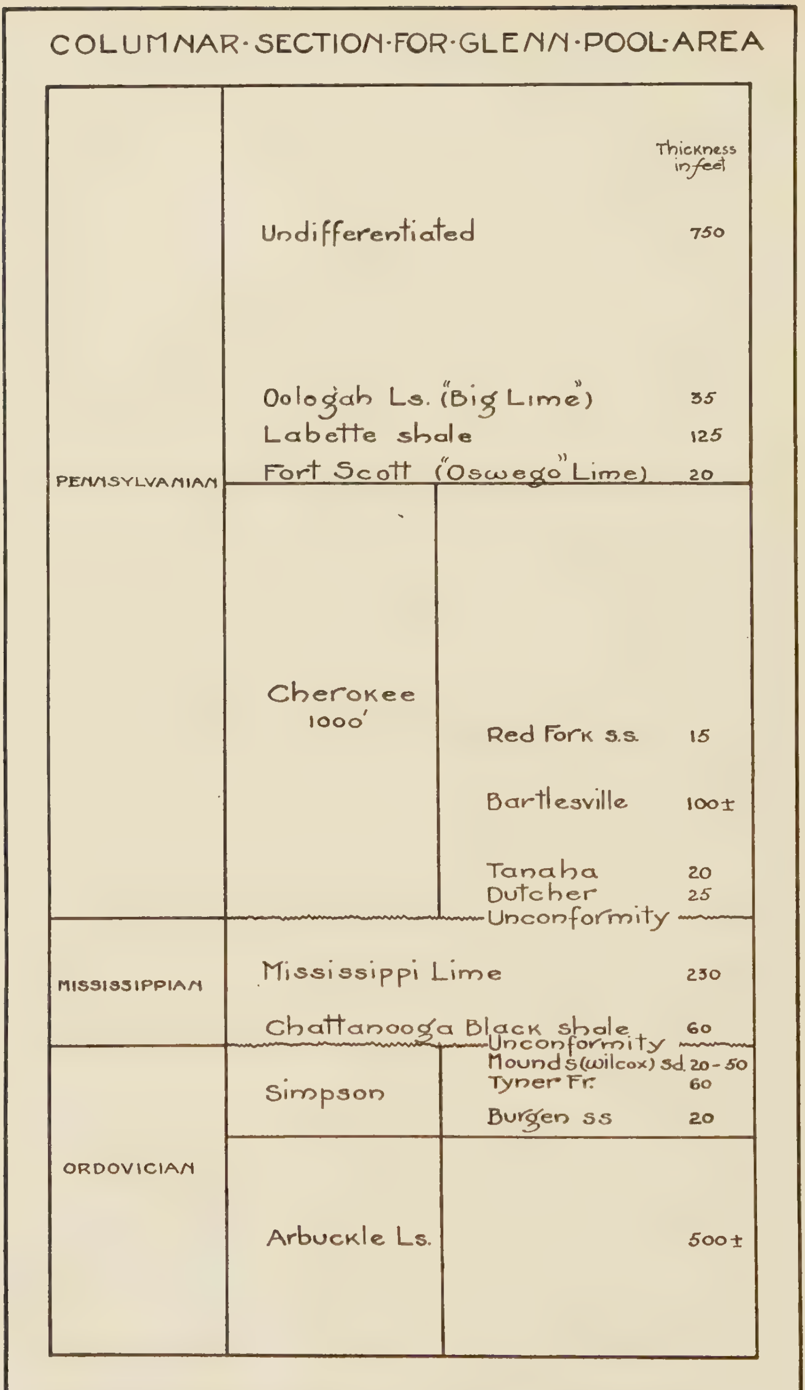

COLUMNAR·SECTION·FOR·GLENN·POOL·AREA
Thickness in feet
PENNSYLVANIAN
Undifferentiated 750
Oologah Ls. ("Big Lime") 35
Labette shale 125
Fort Scott ("Oswego" Lime) 20
Cherokee 1000′
Red Fork s.s. 15
Bartlesville 100±
Tanaha 20
Dutcher 25
Unconformity
MISSISSIPPIAN
Mississippi Lime 230
Chattanooga Black shale 60
Unconformity
ORDOVICIAN
Simpson
Mounds (wilcox) sd. 20-50
Tyner Fr. 60
Burgen ss 20
Arbuckle Ls. 500±

FIG. 1

nology of geologists and drillers familiar with this area. However, the writer believes that the nomenclature is essentially correct, though there is a question as to whether the "Big lime," so called by the drillers, is really the equivalent of the Oologah at its type locality. The reader should bear in mind that the field was practically drilled up twenty years ago and that well logs and other data were recorded at that time most inadequately. In most cases sand records only were preserved, and the saving of well cuttings was unknown.

MISSISSIPPIAN

In recent years several old wells throughout the field have been deepened from the Bartlesville sand and several new deep tests have been completed. The logs and cuttings from these sources permit rather satisfactory identifications of the stratigraphic units. The classification of the pre-Pennsylvanian rocks given in Figure 3 is based on a study of well cuttings by Charles Ryniker, of the Gypsy Oil Company.

Unconformably under the Pennsylvanian are about 300 feet of Mississippian limestone and shale beds. The limestone is probably the equivalent of the Mayes limestone of the Hunton arch, and the underlying black shale is referred to the Chattanooga. In several wells in this general area a few feet of calcareous shale is present between the Chattanooga and the overlying lime. This shale may be a representative of Kinderhook age, but the writer has not felt justified in including it as such in the generalized section.

ORDOVICIAN

Unconformably underlying the Mississippian are Ordovician beds which have been penetrated by the drill about 600 feet. These are referred to the Simpson and Arbuckle formations of the Arbuckle Mountain section. Presumably the Arbuckle limestone rests upon pre-Cambrian granite, but according to the writer's knowledge the nearest test to reach granite is 8 miles northwest of the pool. This test, which is located in Sec. 22, T. 19 N., R. 11 E., entered granite after passing through about 600 feet of Arbuckle lime.

It will be noticed in Figure 1 that the first sand in the Simpson formation is designated Mounds ("Wilcox"). It is the writer's belief that the sandstone horizon, which is now the most important producer in Oklahoma, should be called Mounds instead of "Wilcox" in all scientific literature. Not only is the name "Wilcox" pre-empted by its use for another formation, but it is now known that this horizon was originally developed in Sec. 29, T. 17 N., R. 12 E. as early as December, 1908, and was then known as the Mounds sand. It was several years later that the discovery

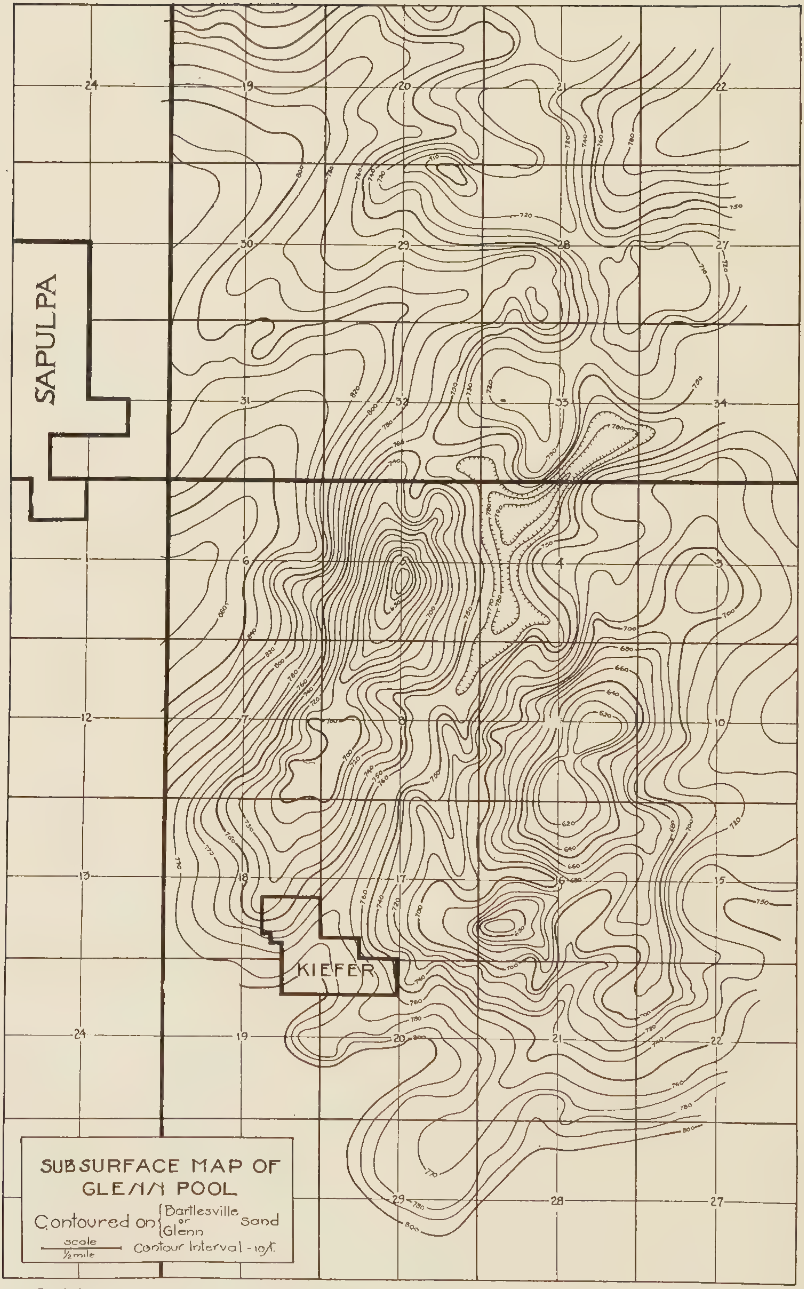


FIG. 2.—Subsurface map of Glenn pool, Oklahoma, contoured on the Bartlesville sand below sea-level.

of oil by the H. F. Wilcox Oil & Gas Company in this horizon in Sec. 4, T. 16 N., R. 13 E. led to the adoption of the name "Wilcox" in popular usage.

SURFACE STRUCTURE

Unfortunately no structure map based on observations on beds exposed at the surface is available to the writer. Perhaps no such map exists. Data were available for subsurface maps of the area before petroleum geologists were employed in Oklahoma, therefore no economic purpose would be served by a map of the surface structure. It is well known, however, that the surface structure of the general area is a monoclinal dip to the west at a rate of about 50 feet per mile. Surface maps of areas adjacent to the pool show local folds, chiefly of an anticlinal or nose type, plunging westward. Structures showing closure at the surface are rare. There is little doubt that throughout the greater part of the pool, local surface structures consist of minor variations from the regional dip, although there is a possibility that careful work with planetable control would show closed surface structures corresponding with the domes in Figure 3.

SUBSURFACE STRUCTURE

As most of the well logs of Glenn pool are sand records only, no attempt was made to construct a subsurface map on a higher datum than the top of the Bartlesville sand (Fig. 2). Contours on the top of that sand show considerable irregularity and several areas of closure when contoured with a 10-foot interval. Only a part of the apparent structure shown in Figure 2 can be attributed to folding. The rest is due to irregularities of deposition, and particularly to the pinching-out of the sand body eastward. Undoubtedly a map on the base of the Bartlesville would be a truer guide to actual structure, but so few wells, particularly in the western part of the field, definitely penetrated the full thickness of the sand body that it is impracticable to construct such a map. Doubtless the closure shown in Sec. 5, T. 17 N., R. 12 E., represents actual doming of the strata, and probably that in Sections 9 and 16 as well.

It is seen that the producing area in the Bartlesville sand shows little if any relation to local folding, since it extends indiscriminately across anticlines and synclines. Nor are the more prolific areas restricted to the areas high structurally or in any definite relation to them. The areas of high recovery are undoubtedly coincident with areas of relatively high porosity in the sand body. As will be shown later, there is good reason to believe that the accumulation in the Bartlesville horizon would have occurred if no local folding had been present.

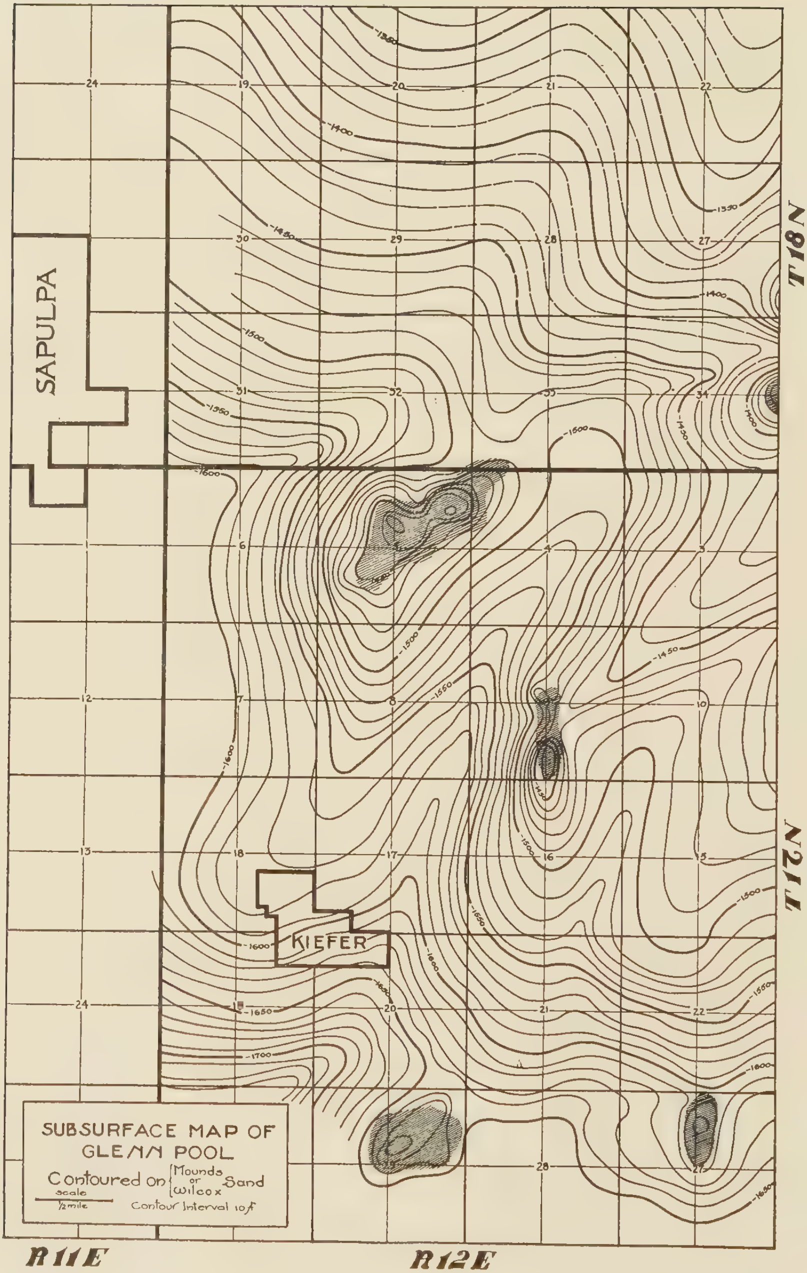


FIG. 3.—Subsurface map of Glenn pool, Oklahoma, contoured on the "Wilcox" sand below sea-level. Shaded portions are areas of "Wilcox" production.

The structure map on the top of the Mounds ("Wilcox") sand is based on far fewer well records than is the case with the Bartlesville sand map, but the records used are the result of later development and are more reliable. The writer believes that the structure shown in Figure 3 is a fairly accurate representation of the structure of the Ordovician beds, and that no other important structures are present. Pronounced doming is present in Sec. 5, T. 17 N., R. 12 E., and along the boundary of Sections 9 and 15. It may be noticed that in these two areas the structures appear to be reflected in the Bartlesville also. Several tests have found production in the Mounds sand on each of these structures, as well as on those in Sections 27 and 29. Referring to Figure 3, the shaded parts show the extent of the development in the deeper sand. However, production from the Ordovician has been disappointing and of little importance. The initial production from the wells has averaged 100 barrels daily or less, and has not been very profitable even at the comparatively shallow depth at which the "pay" is found. Moreover, the oil recovered from the Mounds sand is of low gravity and in all respects inferior to the Bartlesville oil. It may be noticed by referring to Figure 1 that an opportunity was probably afforded for the lighter oil constituents to escape from the Mounds during the period of erosion represented by the unconformity at the top of the sand.

The heavy oil from the Mounds here is an exception to the general rule throughout the northern Mid-Continent that Ordovician oil is of higher grade than that found in the lower Pennsylvanian.

RELATION OF ACCUMULATION TO STRUCTURE

There is no particular problem calling for discussion in the case of the Mounds production. It is restricted to the closed domes throughout the area. Accumulation in the Bartlesville sand is quite different. Oil is present on the local domes and in the synclines between them as well. The writer holds that there is every reason to believe that the pool would have had essentially the same extent and productivity if no local doming or folding were present. All evidence points to a conclusion that accumulation here is due to the pinching-out of the sand body toward the north, northeast, and east.

In Figure 4 is shown an east-west cross section through the main producing area. In the heart of the pool and for many miles on the west and south the thickness of the Bartlesville sand exceeds 100 feet. At or near the eastern limits of production the sand thins practically to zero in a distance of a mile or two. Since the interval from the base of the sand to the "Oswego–Big lime" above is nearly constant, it is clear that

the sand thins from the top. There is an interfingering of sand and shale with the shale content increasing eastward to complete pinching out of the sand. The writer's interpretation of the situation calls for a southern or western source for the sand, which was poured out on the sea bottom and distributed by wave action. In the area east of the pool, the sea in Bartlesville time was too deep for the waves to drag the bottom and thus move the sand along.

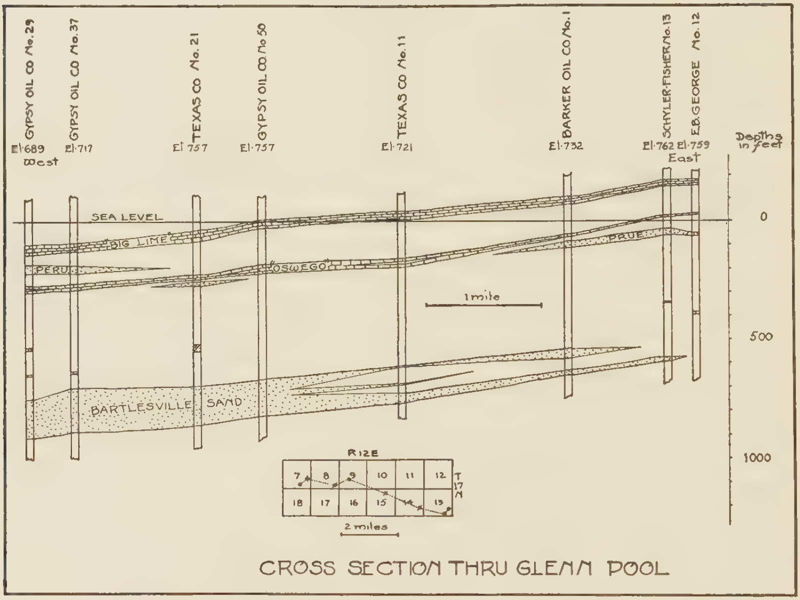


FIG. 4.—West to east cross section through Glenn pool, Oklahoma, showing pinching sands. For relation to producing area, see Figure 5.

The thickness and distribution of the Bartlesville sand body in the pool and its vicinity are shown by an isopach map (Fig. 5) in which the shaded portion is the producing area in the Bartlesville. It will be noticed that the accumulation has adjusted itself in a striking way to the configuration of the sand body along the eastern margin of the field. No production of importance was ever developed where the sand thickness is less than 25 feet. West and south of the pool the sand is present for many miles with a thickness uniformly in excess of 100 feet, but it carries salt water and is referred to by the drillers as the "salt" sand. Along the western margin of the pool the oil conforms to a water level of approximately 950 feet below sea-level.

CAUSE OF ACCUMULATION

The writer considers that the situation in Glenn pool provides a remarkably strong case for the proponents of the theory that lateral migration has been an important factor in many, if not most, of our major oil fields. Certainly lateral migration is the most logical explanation of the accumulation here. There appears to be no reason why oil should ever

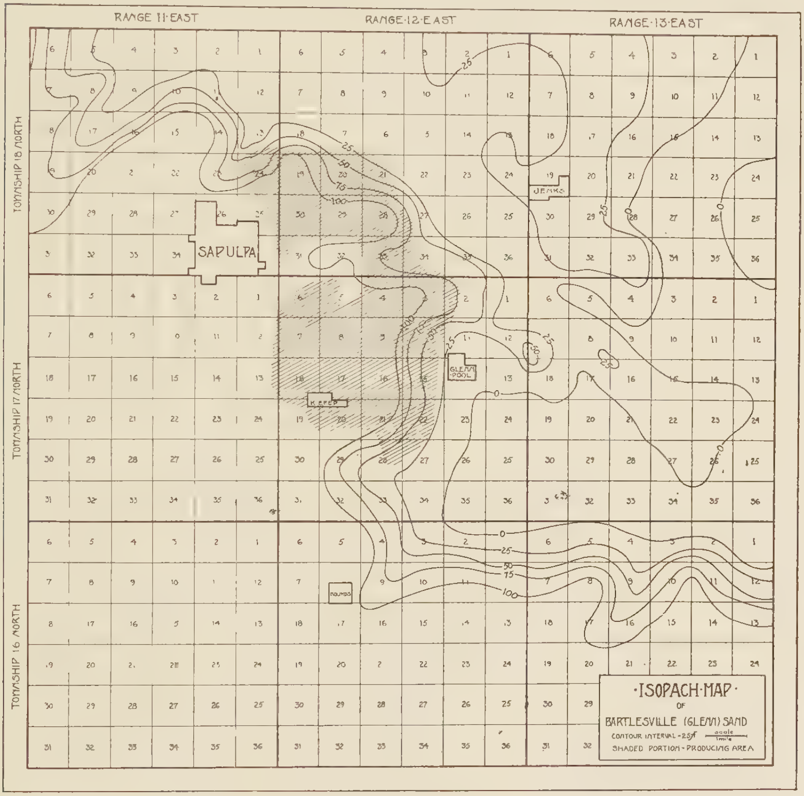


FIG. 5.—Isopach map of the Bartlesville sand, Glenn pool, Oklahoma.

have been generated in exceptionally large quantities locally. Local structures are present, but they are present in equal number and kind in the townships on the south and west for many miles, but on the latter no Bartlesville production of importance has been found, although the area has been intensively tested. Although no reason can be advanced for the generation of exceptional quantities of oil at Glenn pool, the situation is ideal for trapping oil in transit up the dip from the west.

In Glenn pool the situation seems to be similar in all essential respects to barren territory on the south and west, with the one exception that there the Bartlesville sand pinches out, and there an oil field has resulted. The pinching-out of a sand body may not be offered as a reasonable explanation for generating oil, but as the pinching sand affords an excellent trap, the writer feels fully justified in asserting that the trapping action has been dominant. It may be true that many pools of minor importance have been fed from local sources only, but when considering pools with peaks in excess of 100,000 barrels daily, where total production mounts into hundreds of millions of barrels, it is comforting to the writer to call generously upon lateral migration. In passing, it seems worthy of comment that in this locality, in the case of the Mounds sand, which is continuous toward the north and east and is therefore open to migration, the oil accumulation is limited to traps formed by local doming.

Moreover, the situation at Glenn pool, in the writer's judgment, offers some support to the oldest of theories of oil migration, namely, that it moves up the dip due to buoyancy arising from the difference in specific gravity between the oil and the associated water. The migration may never have taken place at a rate that could be detected in a few days or weeks in laboratory experiments. There is no convincing evidence that there has been movement of the water either up or down the dip, carrying oil with it. The chemical character of the waters in the sands of the Glenn pool area is opposed to any reasonable theory of circulation. The waters are brines, and the concentration of total solids in them is several times that of sea water, which above all does not suggest infiltration of meteoric waters from the outcrops. Due to differences of gravity there is a constant pressure tending to drive oil up the dip of inclined strata where it is associated with water. If the action took place so slowly that no oil particle ever responded by advancing more than an inch a year there is no inadequacy of the time factor in accounting for Glenn pool.

DISCUSSION

John L. Rich: Wilson's paper on Glenn pool is extremely interesting and suggestive. It is a brief, but clear, exposition of the geology of the pool, together with a discussion of the scientific problems suggested by the relation of oil accumulation to structure and other geological conditions. If similar papers could be prepared for all oil pools, the gain to the science of petroleum geology would be very great.

In the belief that full discussion of the principles of petroleum geology as applied to specific examples such as those presented in Wilson's paper is highly desirable, and that the presentation of possible interpretations differing from

those suggested may aid in clarifying the problems and in the search for new pertinent data, the following discussion is offered.

In discussing the low gravity of the oil from the Mounds sand, Wilson states: "It may be noticed by referring to Figure 1 that an opportunity was probably afforded for the lighter oil constituents to escape from the Mounds during the period of erosion represented by the unconformity at the top of the sand." This interpretation implies that the oil in the Mounds sand accumulated prior to the erosion represented by the unconformity at its top. If so, this body of oil must have lain essentially at the surface of the ground during the period of erosion represented by the unconformity. This seems very unlikely because such exposure should either have permitted the escape of the oil or have altered it to a tarry residue. Moreover, the Mounds oil is now found on the tops of small closed structures and these structures are reflected reasonably closely in the Bartlesville sand above, as is shown in Figure 2. This indicates that the folding which formed these domes is post-Bartlesville. If these domes in the Ordovician rocks had been present, causing oil accumulation prior to the period of erosion, their higher parts, which now contain the Mounds oil, should have been planed off beneath the unconformity.

Two alternative explanations of the heavy grade of the oil in the Mounds sand beneath the unconformity may be suggested. One is that during the period of erosion represented by the unconformity the rocks then at the surface (such as the Mounds sand) became oxidized, and that after these rocks had been buried and the Mounds sand saturated with oil, these oxidized rocks were reduced by the oil, which was made heavier in the process. A second suggestion is that the oil may have been oxidized by sulphate waters in the present physiographic cycle. It would be interesting to know the nature of the water associated with this oil. Should the water carry considerable sulphate, one would be justified in seeking an explanation of the low grade of the oil in the effect of the artesian circulation of westward-moving meteoric water. Such a circulation would carry sulphate contamination for long distances in a freely porous sand, while a lenticular sand like the Bartlesville might be unaffected.

In looking to other than a strictly local source for the oil of prolific pools like the Glenn, I am fully in accord with Wilson, but lateral migration and accumulation from a considerable area do not, it seems to me, necessarily imply direct up-dip migration due to buoyancy. A similar concentration of oil on the up-dip side of a long and relatively wide sand lens might be effected by a movement of rock fluids containing oil lengthwise of the sand body, in this case, for example, northwestward. In such movement the tendency of the oil to work its way up the dip as it is borne along would always be present, and the total up-dip movement of the oil might well be considerably greater than if the rock fluids were stationary.

Another possible means by which oil might have been concentrated in its present position is by its original migration to the district in a porous lower sand,

such as the Mounds, and its leakage upward into the Bartlesville through fractures associated with one or more of the rather sharply folded structures revealed by the subsurface map of the "Wilcox" (Fig. 3). The present heavier grade of the Mounds oil does not preclude this explanation because it may well be a relatively recent effect of circulating artesian waters. If the oil had originally been widely disseminated through the Bartlesville sand body west and southwest of Glenn pool and had been concentrated on the up-dip margin of this sand body, either, as Wilson suggests, by up-dip migration due to buoyancy or by segregation from rock fluids moving lengthwise of the sand body, as here suggested, it would seem as if all local structures, at least those having "closure," "in the townships on the south and west for many miles," should have caused accumulation of some of this migrating oil. Such reasoning appears to favor the hypothesis of accumulation in the Bartlesville by leakage from below, as does also the seeming lack of oil on the up-dip side of the sand body in other apparently favorable traps along its edge, such, for instance, as in Section 15 and in the W.½ of Sec. 14, T. 18 N., R. 11 E. (Fig. 5).

In discussing the possibility of up-dip migration due to buoyancy, Wilson states: "Migration may never have taken place at a rate that could be detected in a few days or weeks in laboratory experiments"; also, "Due to differences of gravity there is a constant pressure tending to drive oil up the dip of inclined strata where it is associated with water." Admittedly, geologic time is ample for very slow movement to accomplish large results, but what of static friction? A smooth block on a slightly inclined plane will remain stationary indefinitely. Only when the inclination of the plane reaches a certain minimum does movement start. The analogy applies in the case of a bubble of oil in water between sand grains or even on the under side of a smooth inclined plane. Until a certain critical force is exerted, no movement occurs. *Time is not a factor.* A variety of conditions may make possible slow up-dip migration of oil on account of buoyancy, but the effect of static friction and its bearing on the time element should not be overlooked.

SIGNIFICANCE OF STRUCTURE IN THE ACCUMULATION OF OIL IN TENNESSEE[1]

RALPH G. LUSK[2]

ABSTRACT

A review of the data obtained in the several fields in Tennessee which are now producing or have produced oil in commercial quantities shows that in nearly all of them "structure" plays an essential part in the accumulation of oil and gas. Other factors are just as essential and must be taken into consideration. Nearly all of the fields have been mapped in sufficient detail to show the relative importance of the attitude of the beds. Only in the Spring Creek field is this factor apparently of little consequence.

The results of detailed mapping warrant the additional statement that the chances are overwhelmingly against wells located without regard to structure. Not all of the favorable structures drilled have produced oil, but all of the definitely unfavorable structures have been failures.

Anticlinal domes provide oil in the following fields: Celina and vicinity, including Mill Creek and Willow Grove, Spurrier-Riverton, Sumner County, and Tinsleys Bottom. The Glenmary field is on a low-faulted anticline, and the Bone Camp field near Sunbright is on a terrace. The data are none too satisfactory for the Spring Creek field, the Glenmary field, and part of the production of the Willow Grove and Spurrier-Riverton fields.

INTRODUCTION

The oil produced in Tennessee has been obtained from porous or cavernous limestones ranging from 300 feet above to 700 feet below the Chattanooga shale. The strata within this 1,000-foot section are principally of Ordovician and Mississippian age. The oil has been localized in nearly every field by small domes of little closure.

The state of Tennessee, in its great length, extends from the highest part of the southern Appalachians to Mississippi River (Fig. 1). It thus lies across the lines of the southwestward extension of the Cincinnati arch, on the flanks of which are the oil and gas fields of central Ohio and of the Lima, Indiana, area. Moreover, strata and general structure similar to those from which oil is produced in the Cretaceous fields of Arkansas and Louisiana are present on the opposite side of the Mississippi embayment in Tennessee. The development of Tennessee's petroleum resources, however, must be dependent upon painstaking analytical studies

[1] Paper presented by title before the Association at Tulsa, March 26, 1927.

Published by permission of the state geologist of Tennessee. Reprinted from *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 9 (September, 1927), pp. 905–17.

[2] Dr. Lusk died in July, 1927.

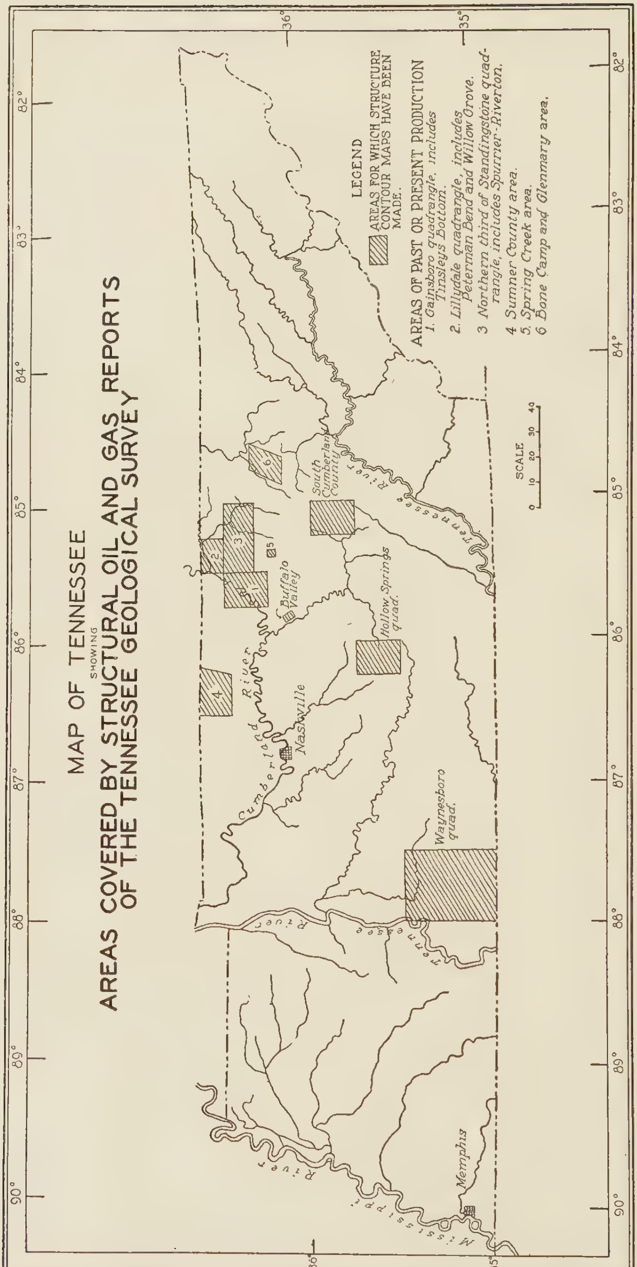

MAP OF TENNESSEE
SHOWING
AREAS COVERED BY STRUCTURAL OIL AND GAS REPORTS
OF THE TENNESSEE GEOLOGICAL SURVEY
LEGEND
AREAS FOR WHICH STRUCTURE CONTOUR MAPS HAVE BEEN MADE.
AREAS OF PAST OR PRESENT PRODUCTION
1. Gainsboro quadrangle, includes Tinsleys Bottom.
2. Lillydale quadrangle, includes Peterman Bend and Willow Grove.
3 Northern third of Standingstone quadrangle, includes Spurrier-Riverton.
4 Sumner County area.
5 Spring Creek area.
6 Bone Camp and Glenmary area.
SCALE
0 10 20 30 40
Nashville
Buffalo Valley
Hollow Springs quad.
Waynesboro quad.
South Cumberland County
Cumberland River
Tennessee River
Mississippi River
Memphis

Fig. 1

of the conditions of the accumulation of the oil that has been produced, and a searching investigation of any problems that may develop as peculiar to oil fields within the state. The writer briefly summarizes the accumulated data pertaining to individual fields with special reference to producing horizons and structure.

PRODUCING HORIZONS AND OIL FIELDS

Rocks from nearly every geologic period are present in Tennessee, but the producing horizons of proved commercial importance are very few (Fig. 2).

KNOX DOLOMITE

Many wells throughout the Central Basin and a few elsewhere in the state have explored the Knox dolomite and have found a few showings of oil and gas. Of the wells reported to have reached that formation, only the Holbert Creek well, drilled in 1921, produced oil or gas in anything like commercial amounts. That well is located on the Sells farm, in the extreme eastern part of Pickett County, two miles northeast of Moodyville. The stratum from which the oil is obtained is 65 feet thick. It is 1,335 feet below the Chattanooga shale and 800 feet below a thin but widespread layer of volcanic ash, referred to by drillers as the "Pencil cave."[1] According to Nelson, who examined samples of the oil and cuttings, this horizon may be the upper Knox dolomite, but is more likely to be a zone slightly above the base of the Ordovician.[2]

ORDOVICIAN HORIZONS

Accepting that conclusion, the oil-yielding beds at Holbert Creek may represent the basal part of the Stones River group in the lowermost Ordovician. Subsurface correlations of Ordovician strata are, however, very unsatisfactory, since as yet no extensive analytical study of drill cuttings has been made. Correlation has been based largely upon depth below the Chattanooga shale or the position relative to the "Pencil cave." The good showing at Holbert Creek has not led to any further discoveries and there is no field producing from this deep horizon.

Showings are reported from several strata higher in the Ordovician system. The lowest horizon of commercial production is at Tinsleys Bot-

[1] Wilbur A. Nelson, "Notes on a Volcanic Ash Bed in the Ordovician of Middle Tennessee," *Tennessee Geol. Survey Bull. 25* (1921), pp. 46–47.

[2] Wilbur A. Nelson, "Description of Oil and Gas Areas in Tennessee and Conditions Affecting New Areas," *ibid.*, pp. 57–58; "The Oil Horizons of Kentucky, Northeastern Mississippi, and Tennessee," *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 8, No. 5 (1924), pp. 622–24.

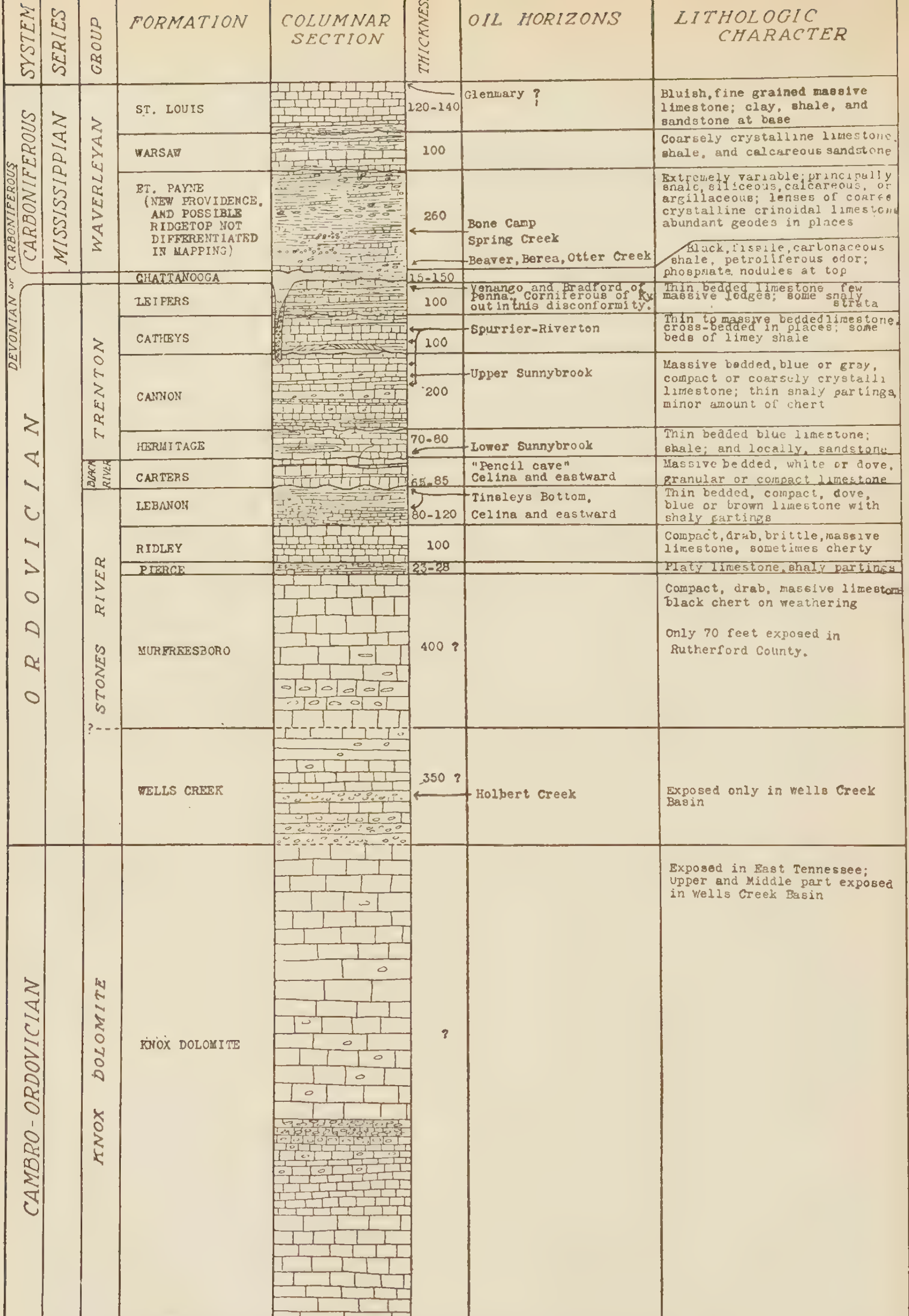


FIG. 2.—Generalized columnar section for northeast-middle Tennessee. Typical of the strata on the northeast flank of the Nashville dome. Rocks below the upper 70 feet of the Murfreesboro formation are not exposed in the Central Basin. The Fort Payne, Warsaw, and St. Louis formations appear at the surface of the Highland Rim Plateau. Six hundred feet of higher Mississippian strata and 600 to 1,200 feet of the lower beds of the Pennsylvanian series are pierced in wells drilled on the Cumberland Plateau before the top of this column is reached. The rocks of the Sumner County area differ slightly from those on the east, for the section on the northwest flank of the Nashville dome includes Silurian strata with a thickness ranging from a few to a few hundred feet; moreover, the upper part of the Ordovician system does not correspond exactly with that shown in this figure.

tom, where the main yield is from a zone 90 to 100 feet in thickness and from 50 to 150 feet below the "Pencil cave." If this bed of volcanic ash is high in the Carters limestone, then, by using the average thickness of strata as measured by Galloway in Rutherford County, this oil-yielding zone may be correlated with the Lebanon limestone.[1] The highest production of importance at Tinsleys Bottom is reported from a zone 50 to 60 feet below the "Pencil cave," which may well represent approximately the contact of the Carters with the Lebanon formation.

Tinsleys Bottom oil field.[2]—The Tinsleys Bottom oil field, developed in 1924–25, is on the Clay-Jackson County line between Celina and Gainesboro. Leipers strata, of Ordovician age, are the oldest rocks appearing at the surface in the immediate area. The Chattanooga shale and younger Mississippian beds are exposed on hillslopes which rise to the surface of the Highland Rim Plateau, here dissected by Cumberland River and its tributaries. Ordovician strata younger than Leipers, and Silurian and Devonian formations, do not appear on the northeast flank of the Nashville dome and are not represented here.

The general structure is a gently plunging northward extension of the Nashville dome. The oil field is located on a well-defined anticlinal fold, as indicated by the elevations of the "Pencil cave" obtained from well logs, and of the Chattanooga shale at outcrops on the adjacent hillsides. The probably productive part of the dome extends about a half-mile east and west, and a quarter of a mile north and south, although only about one-third of the area has been drilled, and its closure probably exceeds 50 feet. The absence of the Chattanooga shale in the area of the dome makes impossible the determination of the date of the folding of the Ordovician strata, which may have occurred either before or after the deposition of the shale. If the data from the "Pencil cave" and dips in the limestone were not available, so that one depended solely upon the elevations of the Chattanooga shale, the area could be contoured as a broad shallow syncline, although the oil field itself would lie in a portion of the region in which the lines would be drawn by extrapolation from surrounding areas.

Shows of oil and limited production have been obtained from 10 to about 300 feet below the "Pencil cave," but, as previously mentioned, the main production is between 50 and 100 feet below this formation, or approximate-

[1] J. J. Galloway, "Geology and Natural Resources of Rutherford County, Tennessee," *Tennessee Geol. Survey Bull. 22* (1919), pp. 30–31.

[2] Joseph R. Roberts, *Tennessee Geol. Survey Press Bull.*, March 15, 1926. Ralph G. Lusk, "Geology and Oil and Gas Resources of the Gainesboro Quadrangle, Tennessee, *ibid.* (report in preparation).

ly 550 to 650 feet below the Chattanooga shale. The history of adjacent wells records the fact that one has interfered with the other; and there is the account of a single well that had been standing with several hundred feet of fluid in it, suddenly becoming dry. This suggests cavernous conditions with interconnecting channels.

In 1925, 8,500 barrels, and in 1926, about 7,000 barrels of oil were produced from this field. This was pumped through the pipe line of the Stoll Oil Refining Company to the town of Windle, which is on the Tennessee, Kentucky, and Northern Railroad. Early in 1926 the production declined to about 15 barrels a day. At the present time no drilling is being done, but activities will probably be resumed in the near future.

The "Pencil cave" formation may be in the upper part of the Carters limestone, which probably attains a thickness of 60 to 80 feet, including 15 to 25 feet of strata above the base of the lower division of the "Pencil cave."

Oil fields of Celina and vicinity.[1]—The general topographic and structural conditions noticed at Tinsleys Bottom are observed in the small areas east of Celina.

The production from the dozen wells at Peterman Bend along Obey River (Fig. 3) is said to be derived from the few feet of strata separating the upper and lower divisions of the "Pencil cave."[2] This small field is on an anticline of slightly smaller dimensions than the one at Tinsleys Bottom.

What may well be the contact of the Hermitage and Carters limestones, 15 to 25 feet above the base of the "Pencil cave," is called the "Second (or lower) Sunnybrook" by local drillers. Production, on which separate figures were not obtained, is derived from this horizon and a still higher horizon, the "First (or upper) Sunnybrook," from small anticlines in the Willow Grove area on Obey River and two small, but well-defined domes on Mill Creek, the latter independently mapped by J. H. McClurkin. The production from Celina and vicinity for 1926 was 6,000 barrels, according to preliminary figures of the United States Bureau of Mines.

The upper Sunnybrook is about 225 feet above the lower Sunnybrook and 250 feet below the Chattanooga shale. This definitely places it in the upper part of the Cannon formation, which was mapped by the writer in the Gainesboro quadrangle during the summer of 1926. The limestone

[1] Gene Perry, *Tennessee Geol. Survey Press Bull.*, Dec. 14, 1925. (With structure map.) Field notes taken by the writer in summer of 1926.

[2] Deepening of these wells has brought in production below the "Pencil cave."

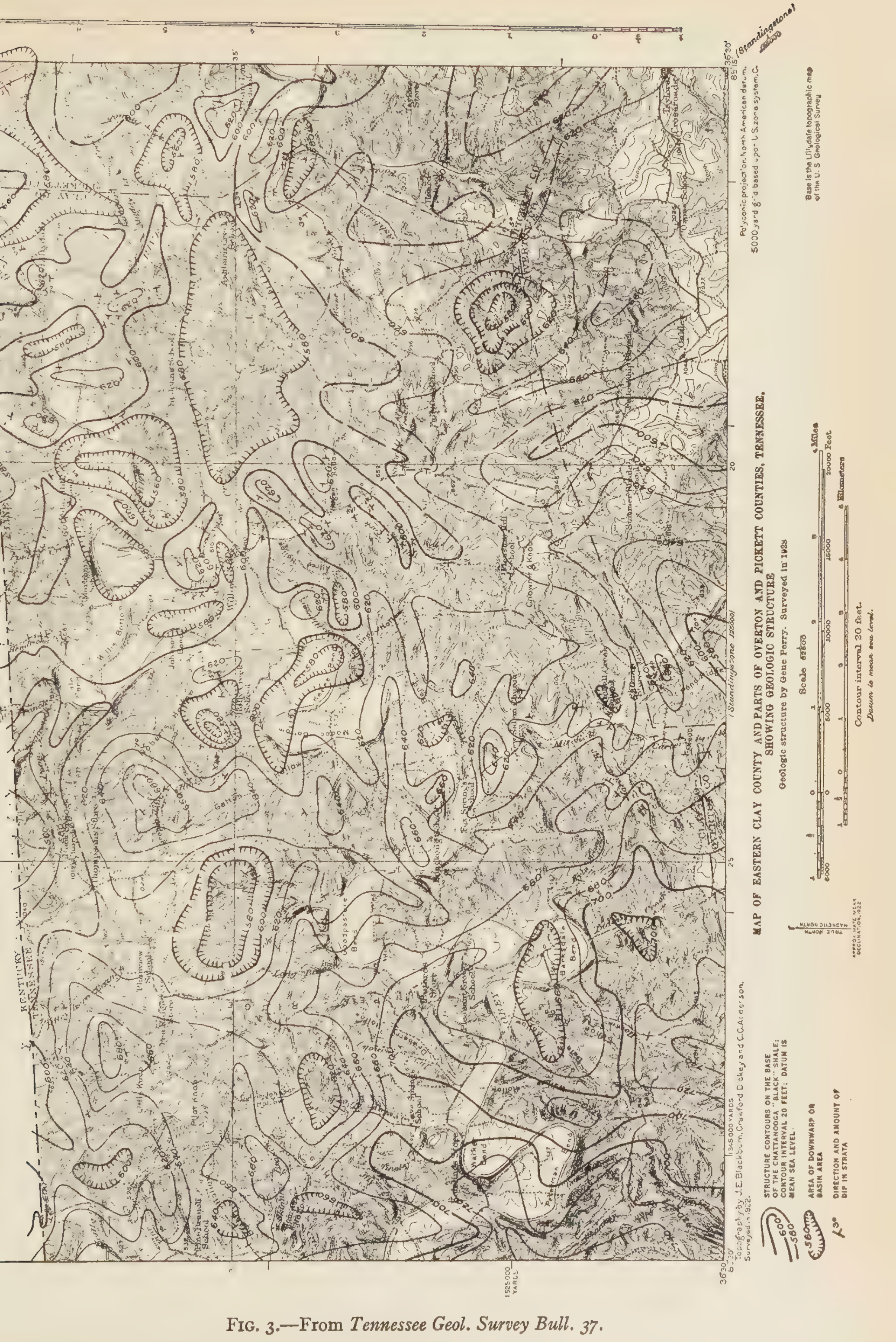


FIG. 3.—From *Tennessee Geol. Survey Bull. 37*.

strata 250 to 265 feet below the Chattanooga shale in Poorhouse Hollow, near Gainesboro, possess a coarse texture, with clear crystals of calcite replacing the plentiful fossils. Some of the fossil cavities are filled with oil. The texture is distinctly granular and so produced by recrystallization with an evident increase in the degree of porosity above that of other beds in the section. This horizon may be recognized at other localities within the quadrangle and probably represents the First Sunnybrook of the drillers. The lower limit of the important production in the Spurrier-Riverton field is at this horizon.

Spurrier-Riverton oil fields.[1]—The Spurrier-Riverton oil field is on the Highland Rim Plateau in Pickett County, 12 miles east and a little north of Livingston. Appearing at the surface are Fort Payne strata of Misssippian age, which overlie the Chattanooga shale. Below the Chattanooga shale lie the Ordovician formations, also encountered by the drill in the Tinsleys Bottom and Celina areas.

According to Butts' structure map, the field appears to be located where the regional dip toward the southeast abruptly increases. There are many folds in the area mapped and their long axes are generally parallel to the Appalachian structure. For the most part the productive wells were drilled on small, closed anticlinal folds. Butts states[2] that he could not be certain about those not definitely shown on favorable structure, for the data were not complete.[3]

The production was derived from at least thirteen horizons within 508 feet of strata below the Chattanooga shale, spaced in descending order about as follows: 20, 34, 65, 106, 146, 170, 206, 230, 267, 309, 409, 460, and 508 feet. The main horizons are between 170 and 267 feet below the Chattanooga shale, hence principally within the Cannon formation, although perhaps in part in the lower strata of Catheys.

Water conditions proved very troublesome in the operation of the wells and would have ruined the field had it not been for the intelligent management of J. H. Compton, pioneering in 1900 with water control in oil production. The first well was drilled in 1892 and about 80,000 barrels of oil has been marketed. A large amount was lost from the phenomenal Bob's Bar well, which ran wild for several months. A combina-

[1] M. J. Munn, "Preliminary Report upon the Oil and Gas Development in Tennessee," *Tennessee Geol. Survey Bull. 2-E* (1911), pp. 9–16; Charles Butts, "Geology and Oil and Gas Possibilities of the Northern Part of Overton County, Tennessee, and of Adjoining Parts of Clay, Pickett and Fentress Counties," *ibid. Bull. 24*, Part 2-A, 1919.

[2] *Op. cit.*, p. 44.

[3] In a recent letter, dated March 24, 1927, J. H. Compton, Riverton, Tennessee, writes that oil occurs in a syncline, where the rocks are dry.

tion of circumstances led to the removal of the pipe line in 1906, following which the field was abandoned. There has been no drilling campaign for several years, but recent reports show a small steady production, and the field is apparently merely waiting for favorable conditions for redevelopment.

SILURIAN AND DEVONIAN HORIZONS

Only in Sumner County have the Silurian strata actually produced oil in commercial amounts. There is no production from Devonian strata in Tennessee. In Sumner County, the "Corniferous" limestone of Devonian age, from which oil is produced in adjacent areas in Kentucky, has not been encountered by the drill and it is wanting from the section in outcrops. There are two "sands" in the strata which represent the Silurian system noted as possible producing horizons, one in the Louisville limestone, immediately underlying and in places as much as 50 feet below the Chattanooga shale, and the other in the Laurel limestone, 50 feet lower.

Sumner County oil field.[1]—The southern third of Sumner County is within the Central Basin, and the remainder is on the northern Highland Rim Plateau. Ordovician limestone strata of the Richmond group are the lowest beds exposed. Above them and below the Chattanooga shale are 125 feet of Silurian strata. Above the Chattanooga shale are formations of lower Mississippian age.

The area is on the northeastern flank of the Nashville dome and the low regional dip is toward the north and northwest. This is modified by local flexures of a square mile or two in area, which have determined the location of oil. Wells not on anticlines have proved failures.

The oil production from Sumner County is a southward extension of the Allen County, Kentucky, field, and is obtained from the Louisville and Laurel limestones not more than 100 feet below the Chattanooga shale. These limestones have been found porous enough to form reservoir beds only in part of the wells drilled in Sumner County.

In 1920 several wells were reported as producing from 4 to 25 barrels of oil per day. There is no current activity.

CARBONIFEROUS HORIZONS

The irregular character of the first 200 to 250 feet of strata above the Chattanooga shale renders correlation difficult and has led to some confusion in the application of the term Fort Payne, for, as used by different authors, it may or may not include Ridgetop and New Providence.

[1] Kirtley F. Mather, "Oil and Gas Resources of the Northeastern Part of Sumner County, Tennessee," *Tennessee Geol. Survey Bull. 24*, Part 2-B, 1920.

The production in the Spring Creek formation was derived from the Fort Payne formation, mainly from strata 120 and 150 feet above the Chattanooga shale. The Bone Camp oil is from a porous limestone near or just below the middle of the Fort Payne formation at a distance of about 75 feet above the Chattanooga shale, while that obtained near Glenmary is found about 325 feet higher, probably at the contact of the St. Louis limestone with the overlying Fredonia oölite. Showings have been reported but no production in other Carboniferous formations.

Spring Creek oil field.[1]—The Spring Creek oil field is in the southern part of Overton County, 10 miles northeast of Cookeville, and about the same distance south of Livingston. It is on the eastern Highland Rim Plateau. Fort Payne strata appear at the surface dipping gently toward the east. In so far as observed, the oil is located without regard to structure, being found in "crevices" in the Fort Payne formation.

The first well was drilled in 1866 near a small oil seep. At 52 feet it ran wild and is reported to have flowed for three months, the oil being lost. About 3,300 barrels of oil were pumped, 2,600 of them from the horizon of 26 feet before the well was deepened. About 7,000 barrels of oil were obtained from the several wells drilled in the first five years. In 1908 and subsequently, attempts were made to reopen the field. There is some activity in the area today, production being sought from the horizons below the Chattanooga.

Glenmary and Bone Camp oil fields.[2]—The oil fields of Scott and Morgan counties are on the Cumberland Plateau section of the Appalachian Plateau province, near its eastern margin, where the coal-bearing formations of the Pennsylvanian series rest upon the eroded upper Mississippian shales of the Pennington formation. Below these shales, the Glen Dean limestone, the Golconda shale, the Cypress sandstone, the Fredonia and Gasper oölites, the St. Louis limestone, the Warsaw and Fort Payne strata are encountered by the drill before the Chattanooga shale is reached, here 15 to 75 feet thick. Underneath are Ordovician limestones, locally separated from the Chattanooga shale by a few feet of Silurian strata.

The regional dip is toward the east but it is interrupted by small folds and a few faults. The Bone Camp oil field is located on a terrace and the

[1] M. J. Munn, "Preliminary Report upon the Oil and Gas Developments in Tennessee," *Tennessee Geol. Survey Bull. 2-E*, pp. 6–9, 1911; "The Spring Creek Oil Fields," *Resources of Tennessee*, Vol. 2, No. 7 (1912), pp. 273–85.

[2] L. C. Glenn, "The Glenmary Oil Fields," *Resources of Tennessee*, Vol. 8 (1918), No. 3, pp. 211–19; Ralph G. Lusk, "The Oil and Gas Possibilities of Morgan County, Tennessee," Report for the *Tennessee Geol. Survey*, in press.

Glenmary field, 4 miles northeast, is on a fold extending about a mile east and west, and cut off on the north by a fault.

The oil in the Bone Camp field is obtained at a depth of 1,400 feet from a porous limestone horizon about the middle of the Fort Payne formation and 75 or 100 feet above the Chattanooga shale. That from the Glenmary field is from strata about 325 feet higher and probably near the top of the St. Louis limestone, where it was rendered cavernous before the deposition of the Fredonia oölite.

Oil was struck near Glenmary in 1916. About 25 wells were drilled in the first few years, but no drilling has been done recently. In 1925, 4,929 barrels of oil were shipped, derived from the 8 wells then producing. In 1926, 3,920 barrels were marketed.

The first well of the Bone Camp field was drilled on the Drake farm in 1924. Several wells were drilled in 1924-25 and the field is still being extended. In 1925, 8,930 barrels, and in 1926, 25,400 barrels of oil were shipped.

There are other anticlines in the area; gas is being obtained from two of them and other tests are in progress.

SUMMARY AND RECOMMENDATIONS

A review of the data obtained in the several fields in Tennessee which are now producing or have produced oil in commercial quantities shows that in nearly all of them "structure" plays an essential part in the accumulation of oil and gas. Nearly all of the fields have been mapped in sufficient detail to show the relative importance of the attitude of the beds. Only in the Spring Creek field does this factor appear to be of little consequence. Domes with greater or less closure have localized oil in the following fields: Tinsleys Bottom; Celina and vicinity, including Mill Creek and Willow Grove; Spurrier-Riverton; and Sumner County. The Glenmary field is on a low-faulted anticline, and the Bone Camp field near Sunbright is on a terrace. The data are none too satisfactory for the Spring Creek field, and for part of the production in the Willow Grove and Spurrier-Riverton fields. That the relationship of oil to favorable structure is not purely fortuitous is established by the fact that in the development of the Bone Camp, Tinsleys Bottom, and other fields the wells located down the dip from areas of production have been failures or very small pumpers.

The results of detailed mapping warrant the statement that the chances are overwhelmingly against wells located without regard to

structure. Not all of the favorable structures drilled have produced oil, but all of the definitely unfavorable structures have been failures.

Judging from the past and present oil fields, the most favorable places to drill for oil are on the northern and eastern Highland Rim Plateau, on the small anticlines on the flanks of the Nashville dome, and on the Cumberland Plateau between Oneida and Crossville.

In the endeavor to promote any possible extension of the areas of production the State Survey has had structure maps made of some areas, or has directed attention toward definite structures in several reports. Some of this mapping as well as part of the work adjacent to oil fields has been more or less of a reconnaissance type to indicate where more detailed work should be carried on before drilling locations are definitely made.

The attitude of the beds (structure) is not the sole factor to be considered in the search for oil. The nature of reservoir beds is exceedingly important. In the adjacent Glenmary and Bone Camp fields production is obtained at distinctly different horizons separated vertically by 325 feet of strata. This indicates that in the Bone Camp field, so far as the Glenmary horizon is concerned, structure is of no significance; conversely in the Glenmary field, wells drilled on the dome below the local production zone have yielded no oil from the Bone Camp "pay."

There is a serious need for field and laboratory studies in which drill cuttings from producing strata may be studied wherever possible in comparison with actual outcrops of the same or similar beds. The evaluation of the relative importance of structure to other factors may then be made. Source beds and the nature of reservoirs in northeast-middle Tennessee are discussed in a report now in preparation for the Tennessee Geological Survey.[1]

The principal areas outside the territory of the oil fields, of which structure maps have been made or in which particular structures have been noted are:

Waynesboro quadrangle: Hugh D. Miser, "Structure of the Waynesboro Quadrangle with Special Reference to Oil and Gas," *Resources of Tennessee*, Vol. 7, No. 4 (1917), pp. 199–219; "Mineral Resources of the Waynesboro Quadrangle, Tennessee," *Tennessee Geol. Survey Bull. 26* (1921), pp. 146–52.

Cumberland County: Charles Butts, "Structure of the Southern Part of Cumberland County, Tennessee, in Relation to the Possible Occurrence of Oil and Gas," *Resources of Tennessee*, Vol. 6, No. 2 (1916), pp. 107–10.

Lillydale quadrangle: Gene Perry, structure map of unpublished report for *Tennessee Geol. Survey*.

[1] Ralph G. Lusk, "Geology and Oil and Gas Resources of Gainesboro Quadrangle, Tennessee," *Tennessee Geol. Survey* (bulletin in preparation).

Hollow Springs quadrangle: R. S. Bassler, structure map of unpublished report.

Benton County: E. S. Perry, "Press Bulletin Report on the Geology and Structural Features of Benton County, Tennessee, as They Affect Oil and Gas Possibilities," *Tennessee Geol. Survey Bull. 25* (1921), pp. 41–45.

Western Tennessee: Wilbur A. Nelson, "Probable Oil Structures in West Tennessee," *ibid. Bull. 23*, Part 1 (1920), pp. 30–38.

West Tennessee River Valley: Carl Dunbar, "Press Bulletin report," *ibid.*, pp. 38–41; "Stratigraphy and Correlation of the Devonian of Western Tennessee," *ibid. Bull. 21* (1919), pp. 21 and 25.

Buffalo Valley: *Tennessee Geol. Survey Press Statement*, July 30, 1926, based on structure map by Ralph G. Lusk.

LULING OIL FIELD, CALDWELL AND GUADALUPE COUNTIES, TEXAS[1]

ERNEST W. BRUCKS[2]
Tampico, Mexico

ABSTRACT

The Luling oil field, in Caldwell and Guadalupe counties, Texas, is on a fault structure about 20 miles southeast of the main Balcones fault. The area is drained by San Marcos River. The Wilcox formation is exposed at the surface and the producing formation is the Edwards limestone of the Comanchean Cretaceous. The field is 7.5 miles long and averages about 0.5 mile wide. The discovery well was brought in on August 14, 1922. On December 31, 1926, there were 502 producing wells in the field.

The structure is a faulted monocline limited on the northwest, northeast, and southwest by faults of about 450 feet displacement. The strike of the structure is northeast. The average heave of the fault measured on the top of the Edwards is about 1,400 feet. The highest points of the structure are near the two extremities of the field, the middle portion being about 40 feet lower. The sedimentary column overlies a metamorphic basement composed of rocks of pre-Comanchean or possibly pre-Cambrian age. The average depth of the top of the Edwards oil horizon is about 2,100 feet. The oil has a gravity of about 27° Bé. The total production of the field to December 31, 1926, was about 31,672,000 barrels, and the daily production about 18,900 barrels.

INTRODUCTION

The Luling field[3] has the unique distinction of being the first, and thus far the only, important oil field in Texas that produces oil from the Edwards limestone of the Comanchean Cretaceous.[4] Vernon E. Woolsey discovered the fault exposure in San Marcos River (Fig. 1), and was the first to recognize the geological significance of the structure. The writer has had the opportunity to study the field in detail since the completion of the Caldwell County discovery well, Rios No. 1, and to work out the northeasterly and southwesterly extensions. He is indebted to Robert L. Cannon for valuable aid in the study of the areal geology and to Sidney Powers, Frederic H. Lahee, and David Donoghue for helpful criticism and encouragement in the preparation of this paper. Vernon E. Woolsey,

[1] Manuscript received by the editor, June, 1927.

[2] Apartado 657.

[3] W. E. Pratt, "Oil at Luling, Caldwell County, Texas," *Bulletin Amer. Assoc. Petrol. Geol.*, Vol 7, No. 2 (March–April, 1923), pp. 182–83.

[4] Since this paper was written oil has been discovered in the Edwards limestone in two new fault-line fields near Luling, the new Luling field in the townsite of Luling and in the Roxana Jolly field 2 miles west of Lockhart. S. P., October 17, 1928.

Carrol E. Cook, and Roy A. Dobbins contributed much information relating to the subsurface geology and the production of the field.

FIG. 1.—Photograph of exposure of the Luling fault plane on San Marcos River.

This paper is a revision of the writer's previous paper[1] on the Luling field, and includes some information that became available during 1925 and 1926.

[1] "The Geology of the San Marcos Quadrangle," *Bulletin Amer. Assoc. Petrol. Geol.*, Vol 11, No. 8 (August, 1927), pp. 825–51.

LOCATION

The field is located in the region of Lower Tertiary rocks, on the Gulf Coastal plain about 20 miles southeast of the main Balcones[1] fault line. With reference to this fault, the position of the field is comparable with that of the Mexia, Wortham, Currie, Powell, and Somerset fields. It lies about 4.5 miles northwest of Luling, Caldwell County, and approximately on a line between Joliet, Caldwell County, and Kingsbury, Guadalupe County. The length of the field from northeast to southwest is about 7.5 miles and its maximum width is about 3,000 feet. The field is accessible by improved roads from Luling, Caldwell County, the most convenient shipping point (Fig. 2).

The Luling field contour map.—This map differs somewhat from the contour map shown in the writer's previous paper on the Luling oil field. It shows the locations of additional wells completed during 1925 and 1926. It indicates the approximate position of the subsurface fault cutting the top of the Edwards northwest of the fault limiting the production along section *C–C* (Fig. 3). This subsurface fault is probably a part of the main fault system, and is postulated to connect at its northeast and southwest ends with segments of the main fault limiting the production toward the northwest.

This map also shows additional cross sections, one at the northeast end and one at the southwest end of the Luling field.

HISTORY

The factor that led to prospecting with the drill in the Luling oil-field region was the northeast-southwest trending fault, which crosses San Marcos River southeast of Prairie Lea, Caldwell County.

The Texas Southern Oil and Lease Syndicate in 1919 and 1920 acquired leases along the projection of this fault and drilled one well, Thompson No. 1, in Caldwell County at a point about 0.5 mile southeast of this fault in the river. Oil showings were encountered in the Eagle Ford shales, but the hole was abandoned at 2,044 feet. On March 18, 1921, this concern was succeeded by the United North and South Oil Company, Inc., which eventually acquired more than 60 per cent of the producing area of the Luling field, and drilling was resumed in the Thompson No. 1 area. In Cartwright No. 1 oil showings were encountered in the Eagle Ford and in the top of the Edwards lime. Similarly, Cartwright No. 2 encountered favorable showings in the Edwards, but

[1] J. A. Udden, "Review of Geology of Texas," *University of Texas Bulletin 44*, 1916.

the locations were too far southeast of the fault to be commercially productive. Further drilling on the Cartwright lands resulted in failure to obtain production. However, on August 10, 1922, the discovery well was brought in on the Rafael Rios lease in Caldwell County, the oil being obtained from the top of the Edwards lime. The first notable extension

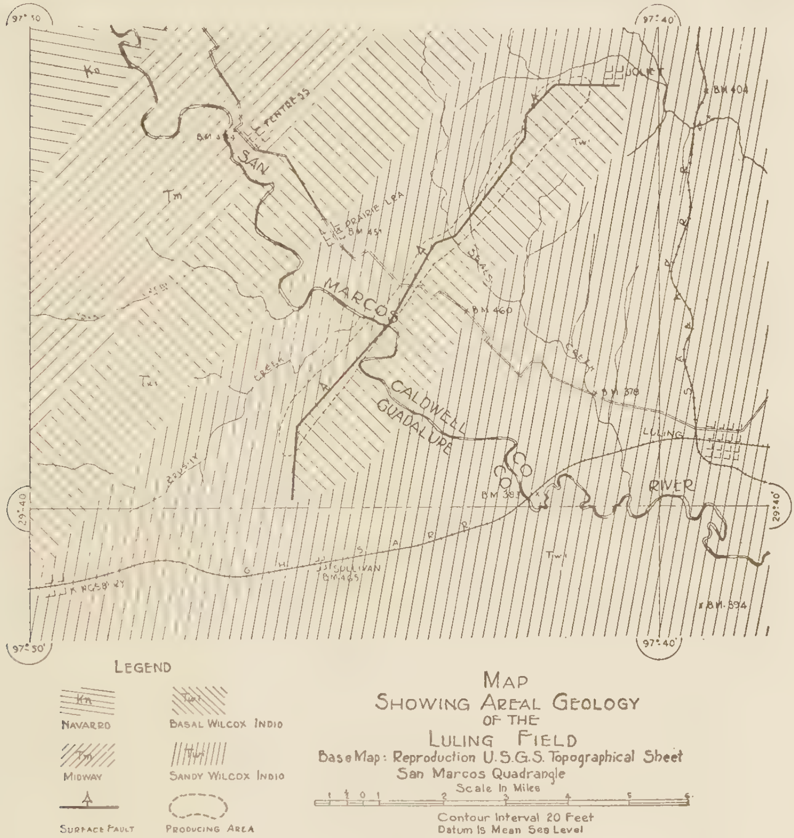


FIG. 2

to the northeast, the Caldwell Oil Company's Hardeman No. 1, was completed on March 13, 1923. It blew in as a gasser spraying about 500 barrels of oil. This was followed on May 23, 1923, by the completion of a 1,400-barrel well on the Royal Oil Company's Tabor 40 acres. The Hardeman well was located about 800 feet northwest of the recognized trace of the surface fault, whereas the Tabor well was located about 1,350 feet southeast of the trace of the fault. Upon the completion of the Tabor

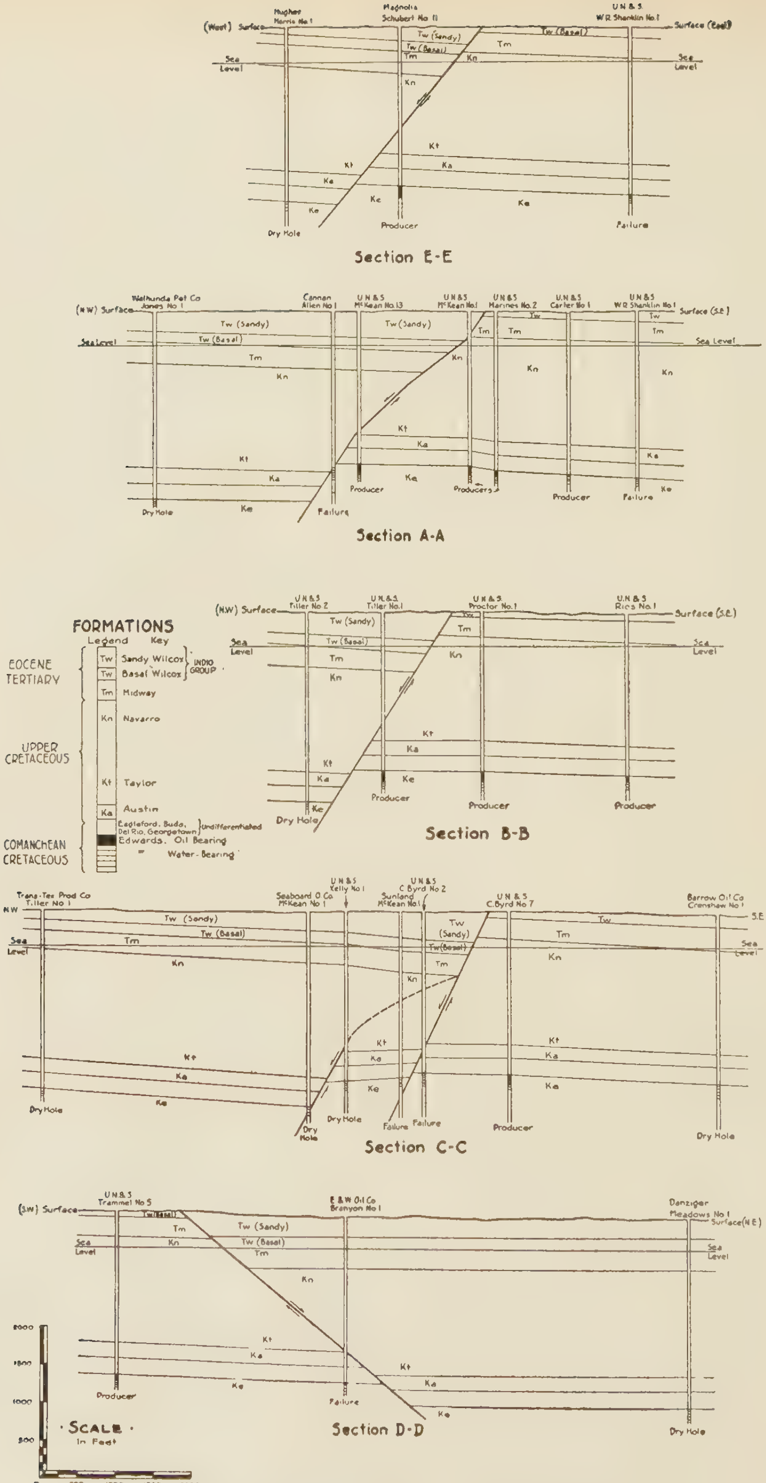


FIG. 3.—Cross sections of Luling field.

well, the field was proved for a distance of about 2.5 miles northeast of the Rios discovery well (Plate 1).

Following the completion of these extensions, drilling increased, and by December 31, 1923, about 90 producers had been completed. One of the most significant developments in the field during the year 1923 was the completion of the United North and South Oil Company's Marines No. 1 in Guadalupe County, an extension of nearly 4 miles southwest of the Rios discovery well. The Marines well was located about 800 feet southeast of the trace of the fault and came in as a 300-barrel producer. On December 31, 1924, the field had 391 producing wells, and by the end of the year 1926, the total number of producing wells was 502.

TOPOGRAPHY AND DRAINAGE

The country about Luling is gently rolling agricultural land, with maximum relief of about 115 feet. The highest surface elevation of producing wells is about 488 feet above sea-level, and the lowest, 373 feet. San Marcos River, flowing in a southeasterly direction, controls the drainage of this area.

There is no conclusive evidence that the fault plane affects the courses of minor drainage channels. However, indurated beds on the northwest side of the fault resist erosion effectively enough to have caused the east fork of Seals Creek to flow in a southwesterly direction, and Brushy Creek to flow in a northeasterly direction. The strike of the strata, rather than that of the fault, controls the directions of the two streams mentioned.

SURFACE GEOLOGY

The normal dip of the surface strata in the vicinity of the field ranges from 1° to 2° SE. The strike of the strata is, in general, parallel to that of the Balcones[1] escarpment at the nearest point and approximates N. 35° E. Variations from the normal southeast dip are due to cross-bedding and structural deformation.

The surface beds belong to the Indio Wilcox[2] formation of Eocene age. Overlying the Wilcox beds in many places are flint gravels of Uvalde or Reynosa age, but in the area covered by the field these gravels are

[1] R. T. Hill and T. W. Vaughan, "Geology of the Edwards Plateau and Rio Grande Plain Adjacent to Austin and San Antonio, Texas, with Reference to Occurrence of Underground Waters," *U.S. Geol. Survey, 18th Annual Report*, 1898.

[2] Alexander Deussen, "Geology of the Coastal Plain of Texas West of the Brazos River," *U. S. Geol. Survey Prof. Paper 126*, 1924. "Geology and Underground Waters of the Southeastern Part of the Texas Coastal Plain," *U. S. Geol. Survey Water Supply Paper 335*, 1914.

residual and do not occupy their normal stratigraphic position. In the Guadalupe County extension adjacent to San Marcos River the Wilcox beds have been eroded and covered with recent flood-plain silts and gravels. The thickness of these flood-plain deposits ranges from a few feet to about 100 feet, their thickness diminishing in a southwesterly direction away from the river channel.

Due to displacement occasioned by the fault, both the basal Indio Wilcox and what is probably middle Indio Wilcox are exposed in the field. In general, the structure is expressed at the surface as a basal Wilcox inlier surrounded by younger Wilcox beds. The strata on the upthrown or southeast side of the fault are of basal Wilcox, whereas the strata on the downthrown or northwest side are of younger Wilcox, the latter being stratigraphically about 400 feet higher in the normal section (Figs. 3, 4, and 5). At the northeastern extremity of the field, the basal Wilcox phase terminates. Due to an east-west cross-fault downthrown on the north, Wilcox sediments of younger age (probably middle Indio) succeed the basal Wilcox phase near Joliet, Caldwell County. Similarly, at the southwestern extremity of the field, the basal Wilcox beds are succeeded by younger Wilcox. Direct surface evidences of a cross-fault are not discernible at the southwest end of the field, but a careful survey of the surface geology reveals strong evidences of a structural "low" abutting the uplifted basal Wilcox beds. Bore-hole data have given additional proof of the structural depressions at the northeastern and southwestern extremities of the field (Plate 1 and Fig. 3). The sections shown in Figures 4 and 5 illustrate the sequence of the strata along the direction of the regional southeastward dip. The Midway-Wilcox contact is found about 3 miles northwest of the fault (Fig. 2).

The basal Indio overlies the joint-clays of the Midway and consists of laminated fine-grained sands and clays, with clays predominating. Irregular zones of impure siderite boulders are found in these beds. The basal Indio is characteristically argillaceous rather than sandy, and weathers to reddish and dark brown clay soils. The predominant perennial vegetation consists typically of mesquite, post oak and blackjack being relatively scarce. Two easily recognized fossils are prominent in the fauna of these beds: *Venericardia planicosta?* and *Ostrea tasex?* The writer has found no pure limestone or *Foraminifera* or petrified wood. The presence of marine fossils and the absence of fossil wood denotes the marine origin of the basal Indio, but the absence of pure limestone and of protozoan fossils identifies these beds as a shallow lagoonal semi-marine deposit.

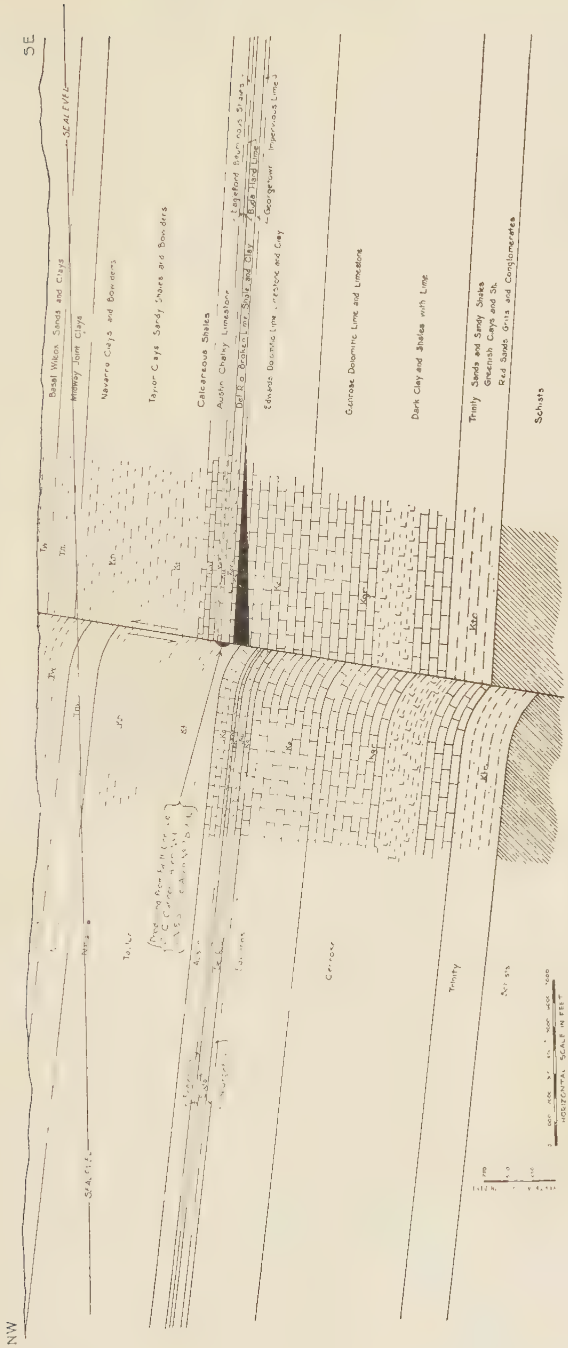


FIG. 4.—Generalized northwest-southeast section, showing the structure and stratigraphy of the Luling fault.

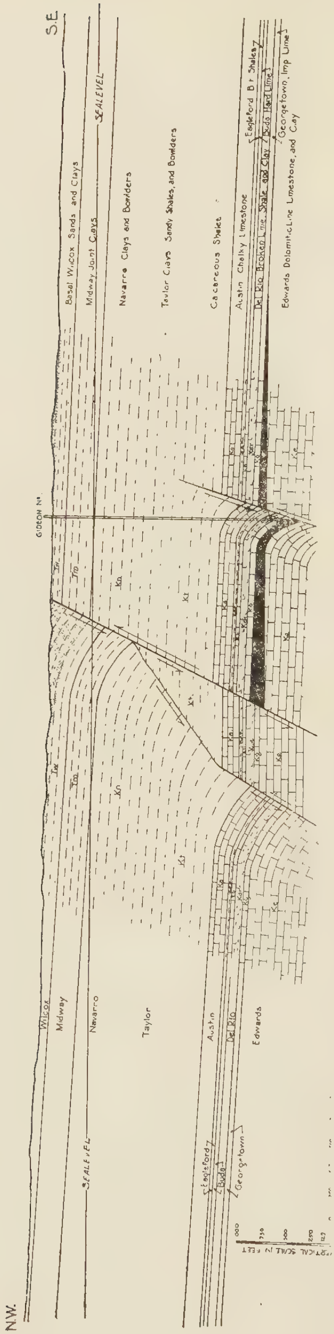


FIG. 5.—Northwest-southeast cross section, showing the compound fault and inferred subsurface structure at Gideon No. 3.

The argillaceous basal beds grade into overlying sandy beds without perceptible unconformity. This sandy member is well exposed on the downthrown, northwestern side of the fault and at the southwestern extremities of the uplift. It succeeds the basal beds on the basinward flank on the southeast side. These beds consist of laminated, micaceous sand and clay and massive cross-bedded sands which in general weather to light and reddish-brown sandy clay soils. Lignite and petrified logs, cone-in-cone concretions, and semi-quartzitic, pyritic, coarse-grained sandstone ledges are characteristic of the sandy phase of the Indio. The hard pyritic sandstone ledges are well exposed on the northwestern side of the fault and form a most reliable key bed. The attitude of the ledges near the fault is abnormal, the strata plunging strongly toward the southeast into the fault plane. This attitude is significant in studying the dynamic geology of the Luling structure. The typical perennial vegetation consists of blackjack and post oak, mesquite being relatively scarce. Fossils other than of petrified wood are apparently absent. The lithologic character and fossil content of this sandy phase of the Indio suggests a lacustrine, continental origin for these sediments.

STRUCTURE

The major structural feature that controls the accumulation of petroleum in the Luling field is a system of N. 35° E.-trending, connected faults having the downthrown side on the northwest. The structure may be designated as a faulted monocline. The dip of the fault plane at the outcrop on San Marcos River is 60° in a direction N. 35° W. Bore-hole data indicate that the dip of the fault plane is about 48° NW. in Guadalupe County and about 65° NW. in Caldwell County northeast of Seals Creek, with a consequent heave of about 1,800 feet and 1,000 feet, respectively, measured on the top of the Edwards pay lime. An exception to this rule occurs on the Tabor and Trammell leases, where the heave of the fault seems to be about 500 feet, and the dip of the fault plane about 80° NW. The displacement of the main fault ranges from 450 to 500 feet. The highest points of the structure are at the extremities of the uplift, the middle portion being 40 feet lower (Plate 1). The abutting of the basal argillaceous Indio on the southeast against the normally superjacent sandy beds on the northwest at the fault exposure indicates a major displacement or throw in the surface beds. The distance in the direction of the normal dip from the top of the basal argillaceous Indio and other markers at their normal stratigraphic position northwest of the fault to the corresponding horizons on the southeast side is about 3

miles. Allowing a southeast dip of 100 feet per mile, the throw in the surface beds would be about 300 feet. However, the dip may be in excess of 100 feet per mile, and since the dip is greatly increased near the fault, the throw may be 400 feet or more. Well data prove that the throw of the major fault measured on the top of the Edwards is nearly 500 feet (Fig. 3). The large amount of cross-bedding in the sandy Indio renders accurate determinations of the normal dip impracticable but it is known that a normal southeast dip prevails from the northwest to within about 1,000 feet of the fault. At this point, the southeastward dip increases gradually to 25 ° SE. at the fault, forming a reverse drag—the opposite of the normal drag. Figures 4 and 5 illustrate the general attitude of the surface strata on both sides of the fault, the strata on the northwest dipping into the fault plane. At the outcrop on San Marcos River a very slight normal northwest drag is observable on the southeast side, but this drag does not seem to persist for a distance greater than 50 feet southeast of the fault. In general, the dip of the upthrown beds is normally southeast, and no strong reversals in dip are observable in the surface beds. However, near Joliet, on the Trammell lease, the dip in the upthrown beds is 5° NE. toward the Joliet cross-fault.

The closure to the Luling structure, as based on surface observations, is afforded on the northwest by the main fault and the accompanying downthrow on that side; on the southeast by the normal basinward depression occasioned by the regional southeast dip; on the northeast by a northeast dip and the Joliet east-west cross-fault and consequent stratigraphic low position; and on the southwest by a north-south cross-fault and a marked stratigraphic depression. These determinations as to closure, made in the fall of 1922, illustrate the value of geology in the interpretation of fault structures.

SUBSURFACE GEOLOGY[1]

Information as to the limits and general conditions of the structure obtained by the drill have confirmed conclusions based on surface geology and in addition have afforded evidence of several unexpected structural conditions not positively reflected in the surface geology.

Available cores of the Austin chalk and the Eagle Ford shale formations, taken from wells on the downthrown side of, and adjacent to, the Luling fault planes, do not show an increased dip. By analogy to the

[1] E. H. Sellards, "The Luling Oil Field in Caldwell County, Texas," *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 8, No. 6 (November–December, 1924), pp. 775–88. "The Producing Horizon in the Rios Well in Caldwell County," *Univ. Texas Bull. 2,239*, November, 1922.

surface condition one would presuppose a steeply inclined bedding plane angle in such cores. The facts that the relatively incompetent Wilcox formation is composed of irregularly alternate layers of thin beds of indurated sandstone and thicker beds of softer sandy clays and clays, and that the subsurface Austin and Eagle Ford formations are composed of massive beds of competent rocks, suggest a reason for the apparent disagreement between the surface and the subsurface beds in this reverse drag phenomenon.

The elastic rebound theory, postulated by Harry Fielding Reid,[1] may afford a reasonable explanation of this reverse-drag phenomenon. The writer is indebted to H. P. Bybee for this reference.

In the United North and South Oil Company's Gideon No. 3 an abnormal deformation was discovered (Fig. 5), the top of the Edwards oil horizon being encountered about 400 feet lower than normal. Cores were taken from the Austin, Eagle Ford, and Edwards, and all of the samples showed an inclination, presumably toward the southeast, of about 45°. In no other wells drilled in the Luling field either on or near the main fault were the cores from the Cretaceous observed to have an abnormal dip. In spite of this seemingly unfavorable condition the well has proved to be a very good producer, the oil being of standard Luling grade. The character of the pay in this well is identical with that of the Edwards pay at its normal level, and the water coming with the oil is of the same quality as that of wells producing from normal levels. Although the vicinity of Gideon No. 3 has been fairly closely drilled, no further evidence of this unusual condition has been discovered. No appreciable vertical displacement is revealed by other wells in this locality; consequently, the condition cannot well be identified as a fault paralleling the main fault, although it has some of the characteristics of a major fault. The fact that the oil in the Gideon No. 3 producing formation had not been replaced by water suggests that the oil may have been present when the deformation occurred, and that the porous beds may have been sealed at the point of deflection from the normal dip by the compacting of the formations at that point.

On the northwestern side of the field in Caldwell County, between the Tiller and W. F. Mercer tracts, well data seem to indicate a compound fault. The producing horizon is cut by a minor fault instead of by the major fault, and a narrow block with the top of the Edwards from 100 to 125 feet lower than the top of the productive Edwards on the southeast seems to lie between this minor fault and the main fault on the north-

[1] *Bull. Department of Geology, Univ. of California*, Vol. 6, No. 19 (1911), pp. 413–44.

west (Plate 1 and Fig. 3). However, the surface geology does not suggest such a condition directly, and the well data available are not complete enough to delimit its extent accurately. The heave of the fault cutting the northwestern edge of production in the area does not seem to exceed 1,000 feet.

Furthermore, the heave of the fault on the Tabor and Trammell tracts, as measured on the top of the Edwards, is estimated to be less than 500 feet. This estimate is based upon the fact that the Tabor No. 23 and Trammell No. 12 wells encountered the fault plane below the normal elevation of the top of the Austin chalk on the upthrown side of the fault. Both wells came in as large gassers at the subsea-level depths of 1,326 and 1,424 feet, repectively; and both wells, after a few weeks, began to produce oil and water of the regular Edwards pay quality along with the gas. This tends to prove that these wells encountered the fault plane at those depths, and that the dip of the fault plane in this area is about 80° NW.

The heave of the Joliet cross-fault is estimated to be about 2,100 feet on the top of the Edwards for the reason that the East and West Oil Company's Branyon test, located about 1,800 feet northeast of the surface fault, revealed a full section from the top of the Austin to the top of the Edwards. Because of a northeast dip in the strata on the upthrown side of this fault, the top of the Edwards in this Branyon test was encountered below the level of the productive oil stratum.

GEOLOGIC COLUMN

The geologic column in the Luling field comprises the formations ranging from the Indio division of the Wilcox downward to and including the Trinity or basement sands of the Lower Cretaceous. A study of the accompanying geologic map and sections reveals the obvious fact that the geologic column of the wells northwest of the fault must of necessity differ materially from that of wells on the southeast. The following descriptions are based on the writer's examination and interpretation of well logs and available cuttings and cores.

The thickness of the basal argillaceous Indio is estimated to be about 50 feet at the surface trace of the fault. The thickness of the sandy beds overlying the basal Indio on the northwest side of the fault is at least 400 feet.

The Midway underlying the Indio is estimated to be about 280 feet thick. A study of the Tertiary section in the United North and South's Tabor No. 16 was made by the writer to determine the thickness of the Midway and Indio (Fig. 6). Accordingly, the thickness of the Tertiary

should be between 330 and 380 feet immediately southeast of the fault, and it is estimated to attain a maximum of about 800 feet on the northwest. The Tertiary beds are drilled with the fishtail bit on the southeast side of the fault and with both the fishtail and the roller bits on the northwest side.

Underlying the base of the Tertiary are found the Navarro-Taylor beds of the Upper Cretaceous. The Navarro and Taylor contact cannot be detected satisfactorily on the basis of lithology and reliable paleontology. The combined thickness of these beds is about 1,350 feet. The beds are of clay and sandy shales and boulders and are readily penetrated with the fishtail bit.

The Austin chalk is the next underlying formation. The top of the Austin is taken by the writer to be the top of the hard limestone underlying the Taylor shales. However, this limestone, though hard, has an earthy, non-crystalline texture. The typical fossil form of the top of the Austin limestone is *Gryphaea aucella. Inoceramus crispii?* is another plentiful form. A peculiar characteristic of the top and the base of the Austin is the presence of glauconite and an oil stain. This formation, logged by drillers as chalk rock, is drilled with roller bits. Pyrite occurs commonly in this formation. The top of the formation is

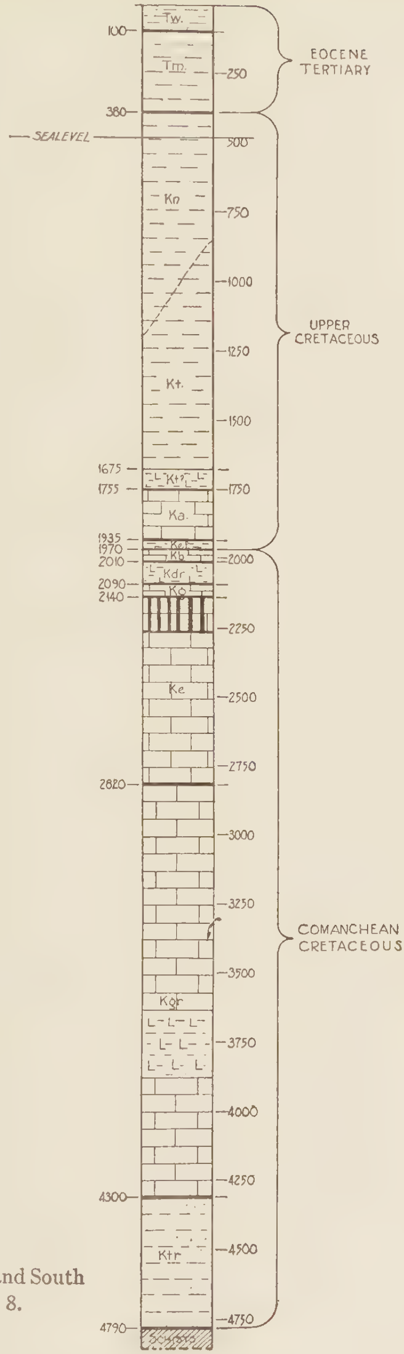


FIG. 6.—Composite log of United North and South Oil Company, Inc., Tabor No. 16 and No. 8.

the most useful horizonmarker above the Edwards lime, and is the best guide in controlling the drilling along the faulted edges of the field.

The succession from the basal Austin chalk into the Eagle Ford formation is marked by a complete change in the character of the rocks. The glauconitic lime of the basal Austin overlies a body of dark, slightly sandy, thinly and evenly laminated bituminous shales of different hardness in which pyrite is common. The Eagle Ford shows considerable gas in the high parts of the structure, and very small quantities of oil of about 35° Bé. gravity are found in this formation, but neither the gas nor the oil is in commercial quantity. The thickness is about 35 feet. Both the fishtail and roller bit penetrate this formation satisfactorily.

The Buda lime, about 40 feet thick, occurs underneath the Eagle Ford. This formation is drilled with the roller bit, as it is too resistant for the fishtail. No readily identified fossils have been observed by the writer.

The contact between the Buda and the underlying Del Rio beds can not be detected satisfactorily with the drill. There seems to be a gradual transition from the hard lime of the Buda into the "broken lime and shale" of the Del Rio. The thickness of the Del Rio is estimated to be about 80 feet. Both the fishtail and the roller bit penetrate these beds, although the latter operates more satisfactorily. Thin limestone ledges occur commonly. The clay and shale of this formation are unevenly laminated and are of a greenish-blue color. Pyrite nodules and pyritized fossils are found. The best guide fossil is a dwarfed form of *Exogyra arietina.*

Underlying the Del Rio is the Georgetown formation, which has a thickness of about 50 feet. The transition from the "broken lime and shale" of the Del Rio to the harder, dense, impure limestone of the Georgetown is very readily perceptible when drilling with the fishtail, but rather indefinite with the roller bit. Although some fossils are found in the Georgetown, the formation can be identified more readily by its lithology and drilling character than its fossil content. Pyrite is scarce. The Georgetown is an impervious limestone and overlies the oil horizon in the top of the Edwards lime.

In the productive portion of the field the top of the Edwards is encountered between the depths of about 1,590 feet and 1,720 feet below sea-level. On the Tabor and McKean lands at the extremities of the field the highest elevation of the Edwards is about 40 feet higher than in the middle of the field (Plate 1). The southeast dip of the top of the Edwards oil horizon ranges from about 200 to 275 feet per mile. The upper Edwards consists in part of dolomitic limestone and shows a porosity of 5–30 per cent or more. The degree of porosity is variable and does not

seem to be controlled by the stratification of the beds. In some wells the top of the "pay" is extremely porous, but in most wells the highly porous formation is 15–30 feet below the top of the "pay." In the major portion of the oil-saturated lime the degree of porosity is uniform and regular. The exceptions consist of irregularly distributed dense, hard, pyritic, chert-bearing limestone lenses about a foot in thickness which are underlain, as a rule, by several feet of very prolific, dolomitic lime "pay."

The initial production of similarly situated wells is extremely variable. The degree of porosity of the "pay," rather than the degree of pressure, seems to be the controlling factor. The pressure is regarded as uniform but a differential porosity affords a variable rate of relief for the pressure, and hence an irregularity in rates of initial production from wells situated similarly with regard to structure. Fossil *Rudistidae*, *Pectinidae*, and *Miliolidae* are fairly well represented in the oil horizon. The thickness of the "pay" ranges from 50 to about 150 feet. The porous character of the Edwards persists below the oil horizon. At about 250 feet below the top of the Edwards the formation is very cavernous and difficult to drill through because of losing returns of the drilling fluid. The total thickness of the Edwards formation seems to be about 730 feet.

No attempt was made by the writer to differentiate the Edwards and the Comanche Peak limestone which normally underlies it. If a clay member comparable with the typical Walnut clay at the outcrop occurs, its identity cannot be established upon lithological or upon available paleontological evidences as revealed by well samples.

The Glenrose formation underlies the Edwards and is about 1,450 feet thick in the Luling field. This formation consists of "broken" dolomitic lime, limestone, and dark shales with little or no pyrite. Fossils are fairly plentiful, and some large *Foraminifera* resembling *Orbitolina texana* have been observed in the upper part. Insignificant stains of heavy oil were found in Chester Byrd No. 2 at a depth of about 3,900 feet in the denser phases of the dolomitic limestone. A test was made of this horizon resulting in a small artesian flow of salt water.

The typical lime phase of the Glenrose is succeeded by a series of white calcareous sands, laminated greenish sandy shales and clays, and red sands and conglomerates with a thickness of about 500 feet. The basal beds are of coarse gravels and conglomerates which appear to be non-fossiliferous and are provisionally classified as the Trinity or basement sands of the Comanchean. At a depth of about 4,600 feet in the Kelley No. 1 deep test, a stratum of oil-stained sand was encountered, which upon testing showed salt water.

In the Tabor No. 8, Kelley No. 1, and Tiller No. 2 wells of the United North and South Oil Company, the 500 feet of the foregoing Trinity sand phase was found to be underlain by varicolored sericitic schists of a talcose texture. These schists have been penetrated to a depth of more than 1,600 feet in the Kelley No. 1 deep test.[1] No granite or other magmatic rock was encountered. The schist, with the exception of the vein-quartz lenses, is of uniform hardness, showing 25°–75° cleavage planes; but at one place, about 1,400 feet below the top, the schist was found to be granular, fragmental, and unconsolidated, and caved readily. No water flows were encountered in the schist. A chemical analysis of the talcose schist does not agree with the talc determination. The schist shows no carbonate and appears to be an aluminum silicate with other metal silicates and oxides in combination. The iron, probably in the form of oxide, lends color to the schist. The analysis of a ferruginous schist sample is given on this page. R. D. Fash, of the Fort Worth Laboratories, analyzed this schist and agrees that the "loss on ignition" may represent water of crystallization.

There is some doubt as to the age of the schists, but it is convenient to designate them pre-Cambrian. However, they may well be of early Mesozoic or of Paleozoic age, and may represent post-Cambrian shales metamorphosed by diastrophism incident to igneous intrusions.

ANALYSIS OF FERRUGINOUS SCHIST FROM WELLS IN THE LULING FIELD

	Percentage
Silica	55.13
Aluminum oxide	27.31
Iron oxide	5.33
Calcium oxide	0.00
Magnesium oxide	1.46
Potassium oxide	3.46
Sodium oxide	1.07
Moisture	0.30
Loss on ignition	6.37

As the igneous intrusions, such as Pilot Knob in Travis County, Texas, seem to be of Cretaceous age, it is probable that several stages of igneous activity may have occurred in the time interval between the pre-Cambrian and the early Cretaceous. The writer indorses the theory that this metamorphism was caused by igneous disturbances of a regional character.

[1] Since this paper was written the Kelley well has been drilled into schist, from 4,723 feet to 7,854 feet, and the Tiller No. 2 from 4,807 to 7,499 feet.

SUMMARY DESCRIPTION OF THE SUBSURFACE SECTION IN THE LULING FIELD

WILCOX EOCENE TERTIARY

Indio.—50–100 feet. On the downthrown side of the surface fault, about 400 feet of sandy Indio strata overlie the basal micaceous, argillaceous beds. These sandy strata consist of soft, micaceous, dark-colored sands and sandy clays interspersed with beds of hard, pyritic, coarse-grained bluish-gray sandstones, this sandy series bearing artesian fresh water. The basal Indio strata are of bluish clay and sandy clay with lenses of hard blue sideritic sandstone. The thickness of the basal beds ranges, in the upthrown side, from a minimum of 50 feet to a full thickness of about 100 feet. Fossils: none observed in well samples; *Foraminifera* seemingly absent.

Midway.—280 feet. Blue clay, practically non-micaceous, bearing globular concretions, the formation being logged by drillers as "clay and boulders." Glauconitic sand is encountered at the base. Fossils from well samples: *Cucullaea macrodonta*, *Nodosaria* sp., *Cristellaria* sp., and others.

UPPER CRETACEOUS

Navarro.—500–600 feet. Blue, non-micaceous, calcareous clays and shales bearing concretions, logged by drillers as "shale and boulders." No distinct horizon markers. Fossils: thin-keeled *Cristellaria* sp., and others.

Taylor—700–800 feet. Upper part of same general character as the Navarro, but the lower strata become increasingly more calcareous. The basal 100 feet consists of bluish-gray, unevenly laminated chalky shale and argillaceous lime of greater hardness than the upper strata. Fossils: marine worm impressions in the basal part, and *Foraminifera.*

Austin.—180 feet. A fairly hard, dense, gray limestone of chalky or earthy non-crystalline texture, bearing small marcasite crystals. Oil stains and glauconite occur in the topmost and the basal horizons. Fossils: *Gryphaea aucella* in topmost stratum, and *Inoceramus crispii* in basal strata.

Eagle Ford.—35 feet. Dark, slightly sandy, evenly laminated, pyritic, rather dense, bituminous shale, generally bearing a little light oil and here and there small volumes of high-pressure gas. The irregular distribution of the gas areas constitutes a drilling hazard southwest of San Marcos River. Fossils: shark teeth.

COMANCHEAN CRETACEOUS

Buda.—40 feet. A relatively pure, non-pyritic, hard dense limestone of flinty texture, showing some glauconite at the top. No fossils observed.

Del Rio.—80 feet. Massive and irregularly laminated, greenish-blue, soft, pyritic clays and shales with thin beds of hard calcareous shales. Fossils: dwarfed *Exogyra arietina*, in places pyritized.

Georgetown.—50 feet. Hard, dense, dark gray, impure limestone with very little pyrite. Forms the impervious cap rock for the Edwards oil horizon. Fossils: *Ostrea carinata*, and others.

Edwards.—730 feet. Upper 50 to 150 feet constitutes the Luling oil zone. Soft, porous, brown dolomitic lime, with beds of soft argillaceous lime of low porosity and irregularly distributed lenses of hard, black, chert-bearing, pyritic limestone. Thin beds of black clay have been reported from the topmost stratum in a few wells. Porosity ranges from 5 to 30 per cent, in general. Large, sulphur water-filled cavities occur about 250 feet below the top, and entire column below the oil stratum is water filled. Fossils: *Rudistidae, Pectinidae, Miliolidae*, and others.

The Comanche Peak limestone and the Walnut clay formations, which normally occur below the Edwards, were not recognized in the Luling subsurface.

Glenrose.—1,450 feet. Hard and soft strata of porous, dark-colored, dolomitic lime bearing salty sulphur water and faint traces of heavy oil; gray limestones; and dark calcareous shale. The average porosity is less than that of the overlying Edwards. The shale beds seem to be irregular in distribution, and rarely attain a thickness of 50 feet. Fossils: *Orbitolina* sp., and *Mollusca.*

Trinity sands or Travis Peak.—500 feet. White calcareous sands and laminated greenish sands and shales, with red sands and conglomerates in basal portion. Faint oil traces encountered in the sandy shales. Basal strata are of coarse grits and conglomerates of schist and vein-quartz derivation. Porosity less than that of the Glenrose, the sands bearing salt water. No fossils observed.

FUNDAMENTAL COMPLEX

Pre-Cambrian schists.—1,600 feet. Red, brown, blue, and gray sericitic schists with lenses of pure quartz and of graphite. Probably of sedimentary origin, the metamorphism occurring in pre-Comanchean time. Total thickness unknown.

DYNAMIC GEOLOGY

It is generally conceded that one of the main forces that caused the Balcones fault lay in the weighting-down of the Upper Cretaceous and Tertiary sediments on the seaward side, operating against the uplifting

tendency of the Central Mineral Region. The action of such forces would logically result in faulting with downthrow on the southeast, such as the main Balcones. However, in the case of the Luling fault and similar structures such as the Mexia-Powell and related faults, the downthrown side is on the northwest—the reverse of what one would expect on the ground of the theory applicable to the main Balcones fault. Moreover, faulting of the Balcones type with the fault plane dipping southeastward would result logically in a shortening or compression of the basinward beds, causing anticlinal structures oriented along the strike of the strata. But the Luling type structures are not true anticlines because there are no extensive reversals in the strata on the northwest. Inasmuch as metamorphic rocks were found underlying the Luling sediments it is strongly suggested that the major uplifting force was supplied locally by a deep-seated intrusion and that the strong southeast dip into the fault plane was caused by the compression on the basinward strata resulting from the Balcones fault action (Figs. 4 and 5). The Gideon No. 3 condition (Fig. 5) also illustrates the theory that a strong compressional force along the direction of the regional dip was exerted on the strata in conjunction probably with the major uplifting forces.

The origin of oil in the Luling field may be explained in part by several theories. However, as the Luling uplift has a minimum closure of 450 feet, and as in this area other faults[1] lacking adequate closure failed to produce oil, it seems probable that ample closure was the prime factor in bringing about accumulation. Inasmuch as the Luling field is the only one producing oil from the Edwards, comparisons cannot be made by the closure, impervious cover, reservoir, and source-rock factors to decide which was the determining factor. In the columnar section, the entire Upper Cretaceous and the Buda, Del Rio, and Georgetown of the Comanchean constituted an impervious cover about 2,000 feet thick. It seems that the 50 feet of impervious Georgetown limestone alone would have served as adequate cover, because in no place was oil found to have stained or infiltrated this limestone; but the presence of at least 500 feet of impervious beds above the Georgetown was essential to provide the closing seal against the Edwards oil horizon on the southwest, northwest, and northeast flanks.

The irregular porosity of the Edwards oil horizon accounts for the erratic occurrence of water with the oil. There is no sharp distinction here between edge water and bottom water, since wells high on structure

[1] E. W. Brucks, "The Geology of the San Marcos Quadrangle," *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 8 (August, 1927), pp. 825–51.

may show water earlier and in larger quantity than the edge wells. The reservoir conditions, therefore, are not altogether ideal. The artificial water-drive method of oil recovery, which is practicable in sands of uniform porosity, would be ineffective and unnecessary at Luling. In fact, the large volume of water here seems to function as a natural flushing agent and tends to promote a maximum recovery. The factors of ample closure, thick impervious cover, and favorable reservoir conditions are easily demonstrated, but the problem of source-rock determinations is not readily solved. The Eagle Ford shales are the only markedly bituminous formation that occupies a position near the oil horizon, the Eagle Ford on the downthrown side abutting the upthrown Edwards. Stains of heavy oil were found in the Glenrose formation in Chester Byrd No. 2; and stains of a medium-gravity oil were found in gray sand and greenish shale of the Trinity sand series in the Kelley No. 1 deep test. However, the Glenrose and the Trinity sands lack the pronounced bituminous character of the Eagle Ford. The Eagle Ford is practically impervious, but shows traces of light oil and gas in every well penetrating this horizon, either in or outside of the structural area.

The oil may be indigenous to the Edwards lime, and the porosity induced by shrinkage upon dolomitization may have afforded passage for the lateral and upward migration of the hydrocarbons into the high parts of the Edwards. Moreover, the process of dolomitization may have freed the hydrocarbons from the organic remains in the Edwards and Glenrose limestones and rendered their accumulation possible. In the Edwards Plateau, traces of asphaltum are reported from portions of the Edwards and Glenrose formations. The theory that the oil was generated or distilled from Trinity or pre-Cretaceous formations by heat from suspected igneous intrusions, and that it migrated up the fault plane for lodgment in the Edwards, finds considerable favor. The fact that gas, oil, and water of the regular Edwards pay quality migrate up the fault plane even higher than the Edwards is demonstrated in several wells on the J. E. Allen "A" lease, in Guadalupe County, on the northwestern side of the field. Again, on the northwest side of the fault, connate and ground waters migrating basinward through the Eagle Ford shales and other bituminous strata may have carried oil, and upon encountering the fault plane may have migrated upward and lodged in the porous upper Edwards. On the southeastern side of the fault, the hydrocarbons and waters in the Eagle Ford shales may have been affected by the process of gravitational separation forcing gas and oil to the higher points at the fault and thence down the fault plane into the porous beds in the Ed-

wards. The gradual accumulation of connate and ground water in the basinward portion of the shales could reasonably have forced considerable quantities of oil into the Edwards along the fault plane. But the oil indigenous to the Eagle Ford has a gravity of about 35° Bé., whereas the gravity of oil from the Edwards is about 27° Bé. In view of these differences it is illogical to regard all the Edwards oil as coming from the Eagle Ford. The Edwards and Glenrose formations, upon dolomitization, may have liberated hydrocarbons. The dolomitization probably occurred after the faulting, because the Edwards on the Edwards Plateau at San Marcos is not dolomitic.[1] The trap formed by the fault may have impounded some of these hydrocarbons from the Edwards and Glenrose. However, if the dolomitization occurred simultaneously on both sides of the fault, forming an open waterway, as is suggested by the present condition, a large part of such hydrocarbons must have vanished through dissemination over extensive areas, or perhaps become concentrated in other pools. The porosity of the Edwards and the lower sedimentaries promoted the invasion and accumulation of the water, and the flushing activity of this mineral water probably liberated the hydrocarbons from the rock, thus forming an avenue for the migration of the hydrocarbons to the fault trap and high point. The history[2] of exploration for other Edwards pools in this area, however, has shown no favorable results thus far.

It is possible that the diastrophism incidental to the faulting may have had a generative action on all possible source rocks cut by the fault, and caused generation and liberation of hydrocarbons in the vicinity of the uplift only.

If Edwards and Glenrose limestones on the upthrown side of the fault were dolomitized long before the corresponding beds on the downthrown side, the hydrocarbons from the Edwards, Glenrose, and Trinity sand could have migrated up the dip of the strata and up the fault plane for lodgment in the upper Edwards reservoir without loss through dissemination in the area northwest of the fault. Only by presupposing imaginary conditions can logical explanations of the origin and accumulation be deduced. It is possible that each of the previously mentioned theories explains in part the origin of the oil.

The occurrence of water is customarily regarded as a damaging factor. However, the important rôle of water in the dynamics of oil migration must not be overlooked. It would seem that the presence of plentiful

[1] E. W. Brucks, "The Geology of the San Marcos Quadrangle," *Bulletin Amer. Assoc. Petrol. Geol.* Vol. 11, No. 8 (August, 1927), pp. 825–51.

[2] E. W. Brucks, *op. cit.*

bottom or edge water, as is the case in the Luling field, is beneficial in that it gradually replaces the oil completely from the bottom and the edges of the reservoir and thus makes for a greater ultimate oil recovery than would be possible without it. The occurrence of water in the Luling field is exceedingly irregular. In some wells water has invaded the highly porous portions of the upper part of the oil horizon, rendering it very difficult to control water encroachment. In several wells the upper "pay" had to be abandoned and the lower "pay" exploited for production. The water appears as early in wells high on the structure as in those on the southeast limit of gusher production. In fact, the wells finally making the most water are those that came in with the largest flush production, regardless of position of the structure. The porosity of the "pay" is irregular both as to degree and areal extent, and seems to be the controlling factor in the volume of daily production from the individual well. Inasmuch as the oil flows more readily from the highly porous portions of the "pay," wells penetrating such highly porous "pays" withdraw the flush oil rapidly, and bottom or edge water follows in the wake of the oil. Since the porosity does not seem to be controlled absolutely by the stratification of the lime, the more porous channels, after being partially depleted of oil, form ready avenues for the entrance of water from the normal edge- or bottom-water levels with which these porous channels may connect. The origin and source of the water should be connected with the origin and migration of the oil, and the theories that are cited for the origin of the oil may explain in a large measure the origin of the water.

CHARACTER OF GAS, OIL, AND WATER

Considerable gas is produced with the oil from wells high on the structure. This gas is of a good fuel quality but contains large quantities of hydrogen sulphide as an impurity. Before the gas can be used profitably in internal combustion engines it has to be passed through water to separate the hydrogen sulphide from it.

The oil has an asphalt base and shows no paraffin. The temperature on an average is about 100° F. The gravity varies from about 26° Bé. in Guadalupe County to 29° Bé. in Caldwell County, the higher gravity oil being found at the northeast end of the field. In general, the gravity of the oil appears to have remained fairly constant. The oil yields about 8 per cent naphtha, 32 per cent gas oil, and 50 per cent light lubricating oil by the ordinary topping process, and there is no free gasoline or kerosene present. Upon high-pressure distillation the oil yields about 55 per cent gasoline, 7 per cent gas oil, and a low grade of fuel-oil residue.

The water has a chlorine content of 5,000–6,000 parts per million. It is slightly saline and has a bitter taste due to the presence of calcium chloride. It is highly charged with calcium bicarbonate and is saturated with hydrogen sulphide. The temperature of the emulsion is higher than that of the water-free oil. As long as a well flows pipe-line oil the temperature is about 100° F., but after the entrance of water the temperature rises slightly above 100° F. There seems to be no appreciable difference between the chlorine content of waters taken from different parts of the field, but the sodium chloride content evidently increases greatly with depth. The waters from the Glenrose and Trinity sands were much saltier than the Edwards waters, and the hydrogen sulphide content was much lower. The water occurring with the oil deposits a thick calcareous (travertine) scale on the tubing and pump rods. In the writer's opinion, all the waters found in the Edwards oil horizon have a common source, hence the practical uniformity in quality.

DEVELOPMENT PROBLEMS

Because of the proximity of San Marcos River, drilling operations were never hampered seriously by the lack of fresh water. Water lines from the river supply all parts of the field.

The principal drilling hazards in the Luling field were encountered on the Guadalupe County side of San Marcos River, where the Eagle Ford shales contained, in places, small volumes of high-pressure gas, causing several bad "blow-outs," and where the fault plane seemed to be open for 300 or 400 feet above the top of the Edwards, causing accumulations of high-pressure "blow-out" gas in the fault plane. In some wells small quantities of gas were encountered in the fault plane at 800 feet below the surface.

The drilling is done exclusively by the rotary method. The great thickness of clays and shales of a caving nature above the Austin chalk renders the use of cable tools impracticable and unprofitable. Ordinarily, a well can be completed in a total time ranging from 10 to 30 days. However, on the northwest side of the surface fault more time is required than on the southwest side because of the occurrence of thick beds of very hard, pyritic Indio sandstone at a shallow depth. As many as four or more sets of roller-bit cutters and cones have been used in some wells to penetrate these sandstones.

On the higher portions of the structure it has seldom been found necessary to swab a well in order to bring it in. Usually a few hours' bailing has served to induce the well to flow. In general, the wells have

been allowed to flow through the casing until production declined to about 100 barrels; then the tubing was run and the production increased by flowing through the tubing. Finally, the wells are put on the pump, the customary method of pumping being by jacks. During the latter part of 1924 many wells were standardized and put on the beam. Shooting with nitroglycerin has been tried with fair success in wells of low initial production from a "pay" of low porosity. In wells where water had intruded to the extent of lowering production very considerably, attempts at water shut-offs were made by plugging back with lead wool. On the whole, this plugging back has been successful in decreasing materially the percentage of water and increasing the production of oil. In several cases the water shut-off was complete and the oil restored to a pipe-line grade.

During 1925 and 1926, electric power for pumping wells was installed on all the properties of the United North and South Oil Company. This change made for greater efficiency in the rapid recovery of the oil, and was instrumental in maintaining the daily production of the field at a higher level that would have been possible without electrification of the power plant.

Two methods of treating the emulsion find favor with the operators in the Luling field: one is by use of Tret-O-Lite, and the other by electrical dehydration. About 80 per cent of the oil is dehydrated by the electrical process. The waste water from the separation processes is allowed to flow into San Marcos River. The volume of fresh water in this river is normally so large that the addition of some 30,000 or more barrels of highly mineralized waste water daily does not seem to make a noticeable difference in the quality of the water of the river downstream from the Luling district.

PRODUCTION

Figure 7 shows the tri-monthly-production and cumulative-production curves and a curve based on number of wells producing each quarter. The curves illustrate the tendencies of oil production over a period from August 14, 1922, to and including December 31, 1926. The initial daily production of wells in the Luling field averages about 900 barrels, the extremes being as low as 50 and as high as 11,500 barrels.

The proved acreage in the field approximates 2,100 acres. The total production of the field was about 15,350,000 barrels on January 31, 1925. The yield per acre, therefore, was about 7,500 barrels up to that time.

On December 31, 1926, however, the total production was 31,672,000 barrels, and the daily production about 18,900 barrels. The total number of wells producing on that date was 502, and the average daily produc-

tion per well was 37.6 barrels. The yield per acre on December 31, 1926, was about 15,550 barrels. Judging from the trend of the production

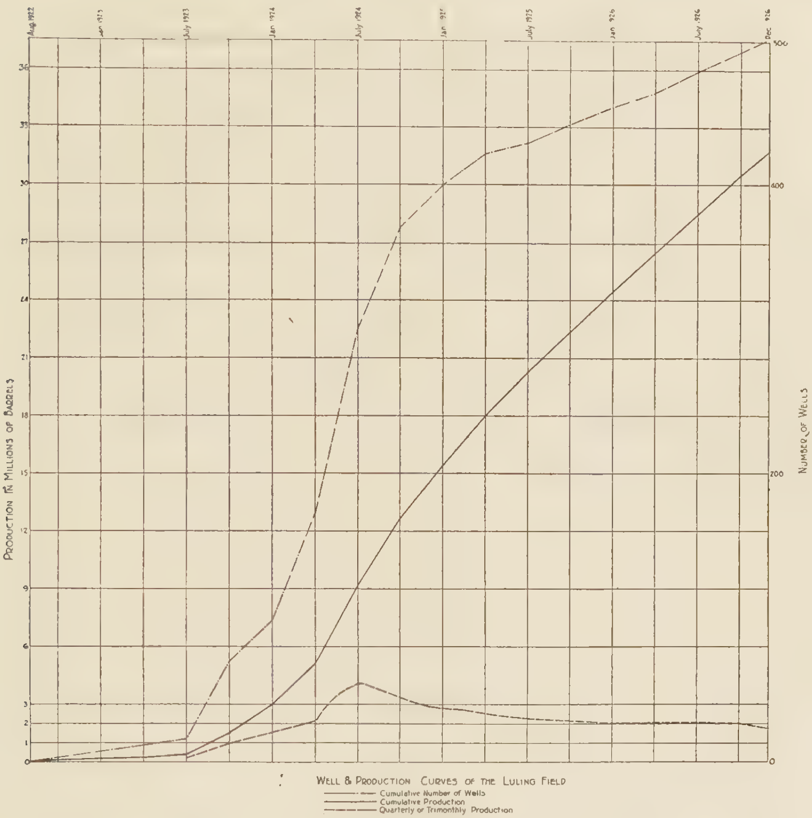


FIG. 7.—Well and production curves of Luling field.

curves one would be led to anticipate an extended period of well-sustained production. The total ultimate recovery from the Luling field will probably exceed 40,000,000 barrels.

WESTBROOK FIELD, MITCHELL COUNTY, TEXAS[1]

E. C. EDWARDS[2] AND LEONARD W. ORYNSKI[3]
Fort Worth and Dallas, Texas

ABSTRACT

The Westbrook oil field is doubly worthy of description because it is the discovery field of western Texas and because oil was found in Permian strata, previously not seriously considered as oil-producing beds. Since the first producer in 1920, a 10-barrel well at 2,498 feet, 77 wells have been drilled, averaging 40 barrels each. Early in 1926, 8 were producing. The Triassic extends from the surface to 500 feet in depth; the remainder of the section is Permian. Several key beds in the Permian are used to map the subsurface structure which is that of a northeast-southwest anticline. The 2,400-foot "pay" and the 3,000-foot "Morrison sand" are themselves good markers, occurring along porous zones within definite vertical limits. The productive reservoir is dolomitic limestone. The oil has a gravity of 25.8° Bé., and contains 4 per cent sulphur, and 32 per cent gasoline. Its source is probably the Permian limestones and shales. Two kinds of gas occur in the field: (1) non-inflammable gas at depths between 1,000 and 1,300 feet and (2) wet petroleum gas in both oil zones.

INTRODUCTION

The Westbrook field in Mitchell County, Texas, is worthy of special reference since it was the first commercial pool to be discovered in West Texas. In addition to being the discovery pool, it has remained of interest because the oil encountered was obtained from strata of the Permian, previously thought to be of little consequence as an oil producer.

LOCATION AND EXTENT

The Westbrook field is located about two miles northwest of the town of Westbrook, Mitchell County, Texas (Fig. 1).

In its present development, it is about 6½ miles long and 1½ miles wide, and has a general northeast-southwest alignment.

HISTORY OF THE FIELD

The first well to be drilled in the Westbrook field was the Texas and Pacific's Abrams No. 1. This well is located in the extreme northwest cor-

[1] Presented before the Association at the Dallas meeting, March, 1926. Manuscript received by the editor, February 3, 1927. Reprinted from *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 5 (May, 1927), pp. 467–76.

[2] The Superior Oil Corporation

[3] The California Company.

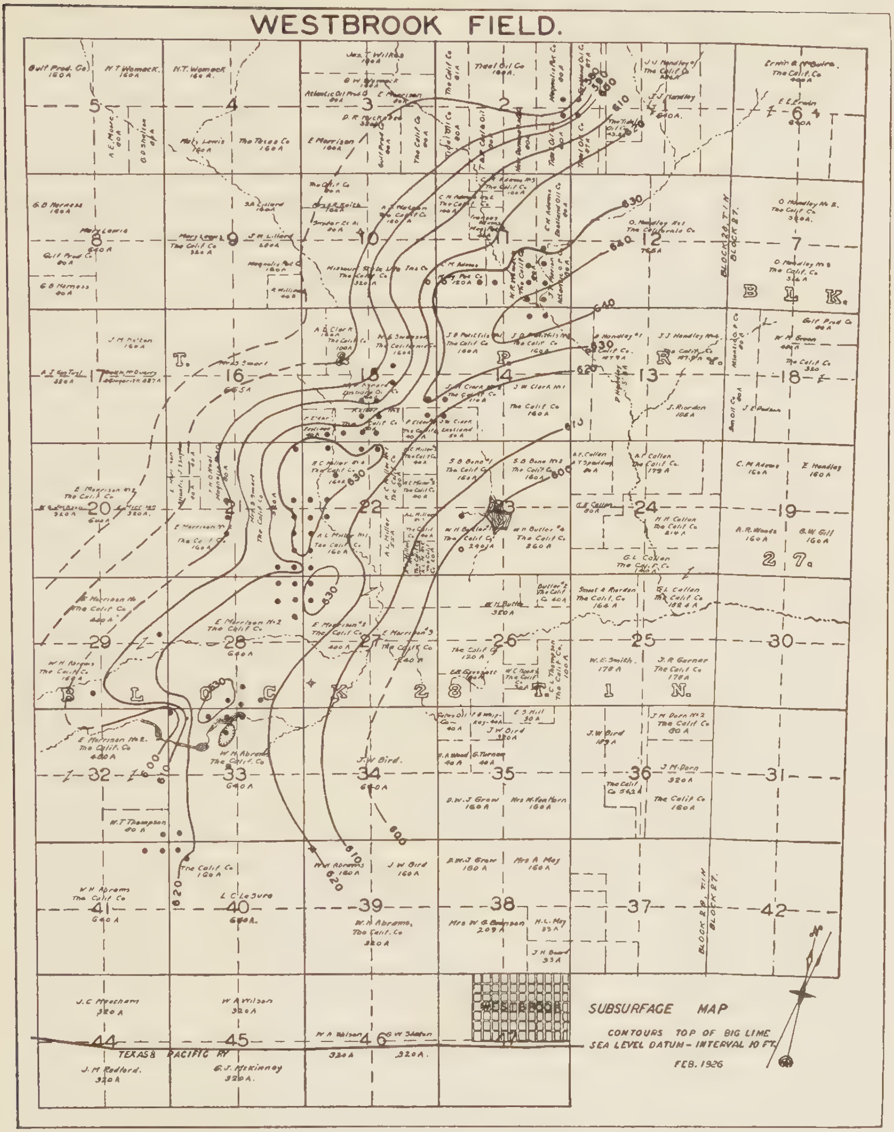


FIG. 1.—Subsurface map of Westbrook field, Mitchell County, Texas. Contours on the top of the "Big lime."

ner of Sec. 33, Block 28, T. 1 N. It is stated that this was not the original location selected for the well, but it was made here due to the fact that the wagon hauling the boiler to the location bogged down at this point. As the boiler had to be taken off, it was decided to change the location and drill the well at its present site. The Underwriters Producing Company drilled the Abrams No. 1 well. It was spudded in, February 8, 1920, and completed March 5, 1921, as a 10-barrel pumper, with a total depth of 2,498 feet. The production came from a brown dolomitic limestone from 2,348 to 2,498 feet. This well was later deepened to about 3,000 feet by The California Company and is now producing from the lower pay horizon.

The second well to be drilled was the Morrison No. 1. This well is located in the northeast corner of Sec. 32, Block 28, T. 1 N. It was spudded in, May 28, 1920, but was drilled only to 440 feet to test a shallow showing which had been encountered in drilling the Texas and Pacific's Abrams No. 1 well. It was abandoned at that depth and later used as a water well.

The Morrison No. 2 was the next well to be drilled. It is located in the southwest corner of the SE. $\frac{1}{4}$ of Sec. 28, Block 28, T. 1 N. This well was spudded in, October 25, 1920, and completed to a depth of 2,425 feet, January 9, 1921. It was drilled by the Underwriters Producing Company. The initial production was 15 barrels, but the well soon settled to a 3-barrel pumper. It was later deepened and a lower pay horizon of brown dolomitic limestone encountered from 2,916 to 2,952 feet. This pay horizon was called the "Morrison sand" from the fact that it was first encountered in the Morrison well. The Morrison No. 2 was drilled to a total depth of 2,972 feet and completed April 1, 1921. The well flowed by heads at the rate of about 50 barrels a day, but after some water trouble was overcome and the well put on the pump, it had an initial production of 200 barrels of oil a day. This well has been one of the best wells in the field and has produced about 120,000 barrels of oil. It is still producing 40 barrels a day.

The next well to be drilled was the Le Sure No. 1, located in the northwest corner of the NE. $\frac{1}{4}$ of Sec. 40, Block 28, T. 1 N., which was spudded in, April 15, 1922. Its total depth was 3,070 feet and its initial production, 50 barrels. This well extended the field about one mile southwest.

The Texas and Pacific Company's Abrams No. 2, located in the northwest corner of the NE. $\frac{1}{4}$ of Sec. 33, Block 28, T. 1 N., offsetting the Morrison No. 2, was commenced April 22, 1922. It was completed November 4, 1922, as a 15-barrel pumper at a total depth of 3,174 feet. This

production was later increased to about 30 barrels and still later to 60 barrels, when the well was reconditioned by The California Company.

The Smart No. 1 well, drilled by Sam Sloan *et al.*, located in the southeast corner of the SE. $\frac{1}{4}$ of Sec. 21, Block 28, T. 1 N., was commenced December 2, 1922, and completed April 13, 1923, at a total depth of 2,980 feet. This well's initial production was 150 barrels. The well was later deepened to 3,030 feet after the production had declined considerably and was reconditioned September 2, 1923, as a 150-barrel pumper. This well extended the field one mile northeast from the discovery well.

The C. F. Kelsey *et al.*, Badgett No. 1 well, located in the northeast corner of the SE. $\frac{1}{4}$ of Sec. 2, Block 28, T. 1 N., was spudded in, November 11, 1922. The well was completed January 2, 1924, as a 50-barrel pumper at a total depth of 3,064 feet. This well extended the field 5 miles northeast from the old Morrison No. 2 well.

In December, 1922, the holdings of the Underwriters Producing Company were taken over by The California Company and since that time several wells have been drilled, most of which have been along the northeast extension from the Morrison No. 2 well.

There are now 77 producing wells in the Westbrook field with a total daily production of about 3,400 barrels, making an average daily production of about 45 barrels a well. At present, March 26, 1926, there are 8 wells drilling.

TOPOGRAPHY

The field lies on a nearly flat plain with here and there small hills of Triassic sandstone and conglomerate, rising 20 to 30 feet above the general level. Small intermittent creeks drain eastward into Colorado River.

GEOLOGY

Areal geology.—The formations exposed in the vicinity of the Westbrook field, and in fact throughout the greater part of Mitchell County, consist of red and gray sandstones and red shales of Triassic age, covered in part by more recent deposits.

The Triassic formations as shown by the well cuttings have a total thickness ranging from 400 to 500 feet.

The lithology of the Triassic is that of reddish to gray micaceous sandstone, and in places conglomerate with blue and red shale breaks 10 to 20 feet thick. The base of the Triassic is marked by a water horizon.

Subsurface geology.—Underlying the Triassic is the Permian series. Extending from 500 feet below the surface to 1,500 feet, the Permian consists of red sand and shale, salt, gypsum, and anhydrite. Below 1,500

feet the Permian series consists almost entirely of dolomitic limestone. From our present correlation, the Permian formation from the base of the Triassic to 2,200 or 2,300 feet is placed in the Double Mountain

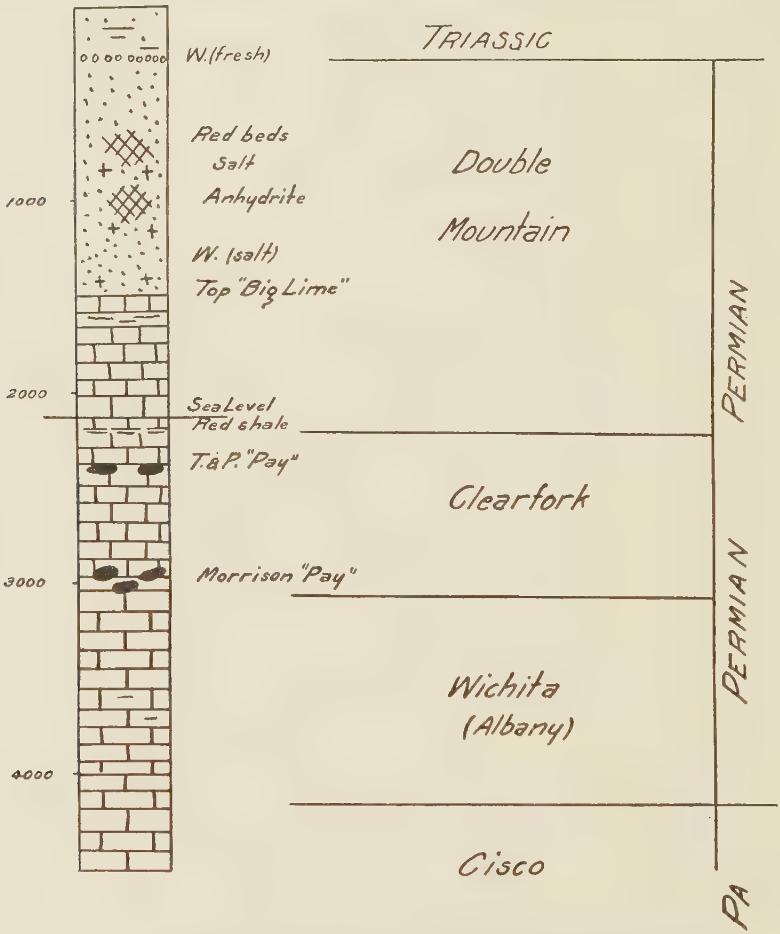


FIG. 2.—Type log for Westbrook field, Mitchell County, Texas.

epoch. From 2,200 or 2,300 feet to about 3,200 feet, it is believed to be Clear Fork; from 3,200 feet to about 4,200 feet, Wichita. Below this is Cisco, of Pennsylvanian age (Fig. 2).

The 2,400-foot "pay" discovered in the Texas and Pacific Company's Abrams No. 1 well probably occurs near the Double Mountain–Clear Fork contact.

If this correlation is correct, the "Morrison sand" or main pay horizon occurs near the base of the Clear Fork.

Although the Morrison 3–No. 1A well, located in the southwest corner of Sec. 27, Block 28, T. 1 N., T. & P. Survey, was drilled to a depth of 5,305 feet, no further pay horizon was encountered below the "Morrison sand."

Surface structure.—In the immediate vicinity of the Westbrook field no surface structure has been mapped. The Triassic beds have only a regional dip northwest. Surface structures have been mapped in the Triassic formation at several places in Mitchell and Scurry counties, but from subsequent developments, these have all been proved not to be reflections of the subsurface structures influencing the accumulation of the oil.

Subsurface structure.—The subsurface structure of the field, based on a key horizon in the Permian, as can be seen from the accompanying structural map, is a long, very irregular anticline with a northeast-southwest trend in the form of a bow.

The east side of the field shows a definite reversal of at least 30 feet. It is believed that the reversal in the Permian on the east side of the field is not very great because of the regional relationship to wells which have been drilled beyond the limits of the map presented. In addition to the slight reversal which occurs on the east side of the field it is evident from the behavior of the wells along this side of the field that the pay horizon does not have the same porosity as that found in the wells on the west. These two factors determine the limit of production along the east side.

Neither the northeast nor the southwest end of the field can be defined at this time because no wells have been drilled close enough to show the limits of the field in these directions. The south end of the field is a few feet lower structurally than the north end, and it is believed quite possible that the anticline plunges slowly and irregularly in that direction. The next control in a northeast direction from the producing field is the Fensland's Badgett No. 1 well located in Section 62, which is a dry hole. This latter well is 140 feet higher structurally than the most northern wells in the field. The steep rise in structure from the Ricker and Womack wells in the north end of the field to the Fensland's Badgett well is far in excess of the rate of rise in the remainder of the field. Two explanations may be given as to what may have happened northeast of the present pool. It is thought that either a fault occurs between the Fensland's Badgett No. 1 and the Womack and Ricker wells, or that the porosity decreases northeast of the field. Under the first hypothesis the field

would be located on the down-drop side of the fault and the oil sealed off from further migration by this fault. If this is found to be true, future wells may prove to be consistently better toward the northeast up to the fault line. If, however, the limit of production in the northeast direction is due to the decrease in porosity in the pay horizon, the wells will then be poorer in that direction. Future drilling is the only method of determining which hypothesis is correct and where the northeast limit of the field may be.

There are four horizons in the Westbrook field which may be used as markers for drawing subsurface maps of the field. At a depth of 1,250 feet, more or less, a water sand occurs in the Red-beds, which is persistent throughout the area. This horizon may be used to contour the field. It occurs about 250 feet stratigraphically above the top of the "Big lime," which is the second best marker on which to contour. The 2,400-foot Texas and Pacific "pay" makes the third marker and the main 3,000-foot "pay," or "Morrison sand," the fourth. The latter two, however, are not very good for depicting the structure of the field, because they do not represent one particular horizon, but occur along porous zones within certain vertical limits. The structure of the Westbrook field as represented on the map accompanying this report has been prepared using the top of the "Big lime" as the key horizon.

OIL

Occurrence.—The reservoir of the Westbrook field consists of two zones in dolomitic limestone containing two or more porous streaks ranging from 10 to 40 feet thick. These zones contain very little sand, 5 per cent at the most. A microscopic examination of the cuttings shows the presence of minute euhedral crystals of quartz such as one finds developed in cavities or vugs. Samples blown from the wells when they are shot show the rock to be a dense, massive, brownish-gray dolomite with almost microscopic cavities and pore spaces. The rock has a mottled appearance because of the presence of many small oval calcite fillings. It is not oölitic, like the Santa Rita "pay" of the Big Lake field in Reagan County.

The origin of the porosity in the productive horizons is an interesting subject for investigation. Three suggestions may be offered. First, the porosity may have developed during the process of dolomitization with its attendant shrinkage in volume of the rock. If the dolomite was laid down as a primary deposit, however, or if the dolomitization process was contemporaneous with the deposition of the lime, the porosity of the pay horizon could not be explained in this way. A second and more reason-

able explanation of the origin of the porosity would seem to be the circulation of underground waters. With the dolomite occurs anhydrite in small amounts in lenses and laminae and intimately intermixed with the dolomite. Underground circulating waters carry away part of the anhydrite through differential solution, leaving the pay zones porous. Some of the porosity of the pay zones is due to incipient fractures in the rock. Samples ejected from the wells when they are shot demonstrate this.

While we may conjecture as to the cause of the porosity of the reservoirs, the known facts about the pay horizons are that they are neither sands nor definite beds, but that they occur as zones within well-defined vertical limits.

The behavior of the wells shows that porosity is not the same in all directions. Offsets drilled near a group of wells will affect some of these producing wells more than others. A very marked decrease in production is noticed in many of the older wells when new ones are drilled in. The degree of porosity is very irregular throughout the field and at present it is impossible to define areas where it could be predicted.

Source.—The source of the oil is probably in the marine Permian limestones and shales. This opinion is based not on observations from the local Westbrook field alone, but from a study of the lithology and character of the Permian sediments in most of west Texas. In speaking of the marine Permian limestone and shales as sources for the oil, we refer specifically to the Wichita-Albany and Clear Fork series, which in many places contain considerable organic material.

Analysis.—The oil is dark brown and is of a mixed paraffin and asphalt base. Analysis shows the following:

Gravity...............	25.8 degrees API. Bé.
Sulphur...............	$3\frac{1}{2}$–4 per cent
Gasoline..............	31.98 per cent

Production.—At the present time there are 77 producing wells in the Westbrook field, with a total production of about 3,400 barrels daily, which makes an average of nearly 45 barrels per well per day.

The wells drilled have had an average initial production of 75 barrels per day. This figure represents the average daily production for the first month of settled production.

The decline of the wells can be ascertained from the accompanying family curve (Fig. 3). This family curve was constructed from the wells of the Kynerd lease. This particular lease was used because it is located in the central part of the field, and represents a fair average of the rate of decline for all of the wells of the field.

It is the practice to shoot all the pay horizons in the field from which production is obtained. This is done because it increases the production greatly, especially where the pay horizon is non-porous and hard. The oil string is landed 150–200 feet above the producing horizon. This is found to be far enough up the hole for the casing to be undisturbed by the shot.

GAS

There are two distinct kinds of gas encountered in the drilling of wells in the Westbrook field: (1) a non-inflammable gas encountered in the

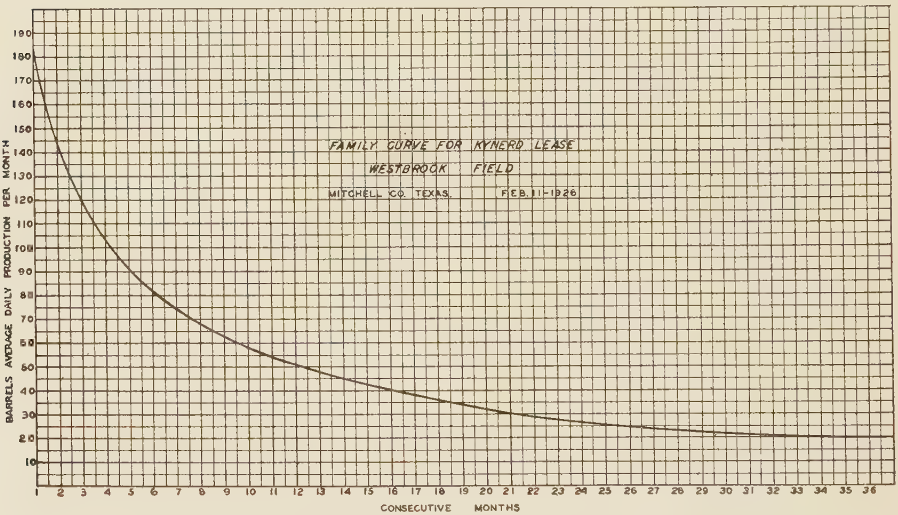


FIG. 3.—Family curve for Kynerd lease, Westbrook field.

Permian Red-bed series at depths between 1,000 and 1,300 feet; (2) a wet petroleum gas occurring with the oil at the two "pays," namely, the 2,400-foot zone, and the 2,925–3,000-foot zone.

Non-inflammable gas.—One of the interesting developments of the field was the non-inflammable gas. The gas was first encountered at 1,035 feet in drilling the Badgett No. 1 well, located in Sec. 62, Block 97, Mitchell County, during the latter part of September, 1922. It was estimated that the flow of gas at this time was about 20,000,000 cubic feet. On deepening the well about 30 feet, another gas horizon was encountered and the flow of gas increased to about 50,000,000 cubic feet. At this time, or shortly thereafter, water was encountered, and the well flowed about 10,000 barrels of salt water per day, in addition to the gas. The well

flowed salt water and gas about five months, then only gas about two months before it exhausted itself or sealed itself off.

The interesting data relative to this gas are here set down.

1. The composition of the gas can be determined from the following analyses:

	Analysis Made for The California Company		Analysis Made for *The Oil Weekly*
	Sample No. 1 Per Cent	Sample No. 2 Per Cent	Sample No. 1 Per Cent
Carbon dioxide	0.2	None	0.1
Oxygen	0.7	1.2	Not given
Methane	14.2	3.2	5.6
Ethane	0.8	None	1.1
Nitrogen	84.1	95.6	93.2
Helium	....	0.014	....

In all of these analyses the nitrogen content is very high, the ethane low, and the methane relatively high.

It would be difficult to attempt to explain the origin of this gas. From its high nitrogen content, its relatively high methane content, and its low oxygen and low carbon dioxide content, the gas may be either of organic origin or trapped air which has undergone some change, or a combination of the two.

2. This gas has been encountered in varying amounts in several of the wells drilled in the Westbrook field and in southern Scurry County. In three of these wells, namely, Badgett No. 1, Sec. 62, Block 97, Mitchell County; Moore No. 1, Sec. 16, Block 97, Scurry County; and Welborn No. 1, Sec. 103, Block 97, Scurry County, the non-inflammable gas was found in sufficiently large quantities to be used in a regular drilling engine for power purposes. The two last-mentioned wells were drilled in this way, and later pumped by the use of this gas. In some of the wells of the Westbrook field the quantity of gas was large enough to have been of value for power purposes, but was in such close contact with a water-bearing stratum just below it, that it had to be mudded and cased off. In the Scurry County wells this objectionable water stratum seems to be absent, and the gas is easily bradenheaded off and used for power. For power purposes, the gas is run into a regulation steam boiler, the safety valve set at the pressure desired and used in the same manner as compressed air. A regular drilling engine was used in all cases, the only changes necessary being the enlarging of the exhaust pipe and the use of low temperature oil for lubrication.

3. The gas sand evidently extends throughout a large area, but at the

present time it is impossible to say whether it will be continuous in this entire area or not. Probably its extent will be very irregular.

4. The gas is colorless, odorless, and non-inflammable. Attempts were made to burn this gas at all of the drilling wells where it was encountered, but it was found to be non-inflammable. In the old Badgett No. 1 well, however, it was set on fire on two different occasions and burned several days each time, with a colorless flame. The gas did not burn directly over the hole, but burned on one side of it where it was passing up through a large mass of salt that had been deposited by evaporation from the supersaturated salt water which had been ejected from the well along with the gas. Since the amounts of oxygen, methane, and ethane in the gas vary considerably, as can be seen from the analyses, it is not known whether the combustion of the gas was due to a change in composition, or to loss of moisture from contact with the salt, or whether the salt had some sort of catalytic action on the gas.

Petroleum gas.—This gas, as previously stated, occurs with the oil. The upper pay horizon carried very little gas, the greatest amount being found with the main "Morrison sand." The gas is very wet and has from 4.25 to 4.75 gallons of gasoline per thousand feet. It has a specific gravity of 0.87 to 0.97.

The amount of gas is variable in the different wells, ranging from an amount so small as to be practically impossible to measure, to 40,000 cubic feet per well per day. The amount of gas is also somewhat irregular from day to day in the same well.

RELATION OF PRODUCTION TO STRUCTURE IN CENTRAL WILBARGER COUNTY, TEXAS[1]

H. B. FUQUA[2] and B. E. THOMPSON[2]
Fort Worth, Texas

ABSTRACT

Oil accumulation in Wilbarger County, Texas, is due primarily to the presence of Pennsylvanian beds upwarped by the Red River uplift of north-central Texas which extends east and west through the county. The stratigraphy may be briefly described as consisting of 1,100 feet of basal Permian, underlain by approximately 1,400 feet of undifferentiated Pennsylvanian, superimposed upon a Cambro-Ordovician and igneous mass. The important producing horizons, of which there are several in each pool, are of Pennsylvanian age. The discovery of the several pools of Wilbarger County may be directly traced to either surface or subsurface geology.

INTRODUCTION

The original stimulus responsible for oil prospecting in Wilbarger County, Texas, was derived from the discovery of shallow oil in a well being drilled for water near the town of Electra, in extreme western Wichita County, which adjoins Wilbarger County on the east. This discovery took place during the year 1908, and The Texas Company (Producers Oil Company) thereafter entered into a contract with W. T. Waggoner under which they were allowed the right to prospect the Waggoner ranch, which embraces approximately the south half of Wilbarger County. Numerous test wells were drilled on this property, in later years under geological direction. During the progress of this development practically every structure covered by this report was tested, but due to failure to drill to sufficient depth in some places, and in others purely to the irony of fate, they failed to reach commercial production except in the extreme eastern part of the ranch along the western flanks of the several Electra pools.

The next important development in Wilbarger County succeeded the revision of The Texas Company–Waggoner contract, when the Sigler Oil Company, consisting of a group of independent operators, developed commercial production in their Waggoner No. 1 well, approximately 12

[1] Read before the Association at the Tulsa meeting, March 26, 1927. Manuscript received by the editor, January 24, 1928.

[2] Gulf Production Company.

miles south of the town of Vernon. This well was completed on July 26, 1920. This development represents the real beginning of the recent intensive activity in the county.

In 1923, upon geological advice of Roy Reynolds, a group of local Vernon business men drilled two wells approximately 9 miles south of the town of Vernon. The second of these, known as the South Vernon Oil Company's Stephens No. 1, was the discovery well of what is now known as the South Vernon pool, which, although small, represents by far the most prolific spot so far developed in the county.

In rapid succession thereafter the following pools were developed: the Landreth pool, which in reality is an eastward extension from the old Sigler well; the Gulf-Waggoner "R" pool, located midway between South Vernon and Electra; the Fluhman pool, located $2\frac{1}{2}$ miles due west of the South Vernon pool, and several other small productive spots of secondary importance.

TOPOGRAPHY

The topography of the area covered in this paper is typical of Permian Red-beds throughout the Middle West, consisting of gently rolling hills with Permian bad lands here and there where eroded by drainage. The streams, practically all of which are intermittent, drain toward the south and east into Beaver Creek, which in turn drains into the Big Wichita River. The average elevation of this area is 1,200 feet above sea-level. The only vegetation of the region consists of a few stunted hackberry and elm trees along the streams, and dry-weather grasses typical of the plains country.

STRATIGRAPHY

For convenience there is shown in Figure 1 an approximate stratigraphic section of the South Vernon field, which is centrally located in the area. On an attached surface structure map (Fig. 2) there is shown a line separating detail work done on sandstones of the Clear Fork formation, and detail work done on limestones of the Wichita-Albany formation, both of Permian age. This line represents the approximate contact between these two formations. No other formations are exposed, with the exception of some recent material west of the South Vernon field.

On account of the South Vernon pool being centrally located in the area under discussion, a type section was assembled from data collected from this field, which shows that there is approximately 200 feet of Clear Fork represented by red shales and a few non-persistent but well-cemented sandstones. Underlying the Clear Fork is approximately 900 feet of Wichita-Albany, consisting of alternating blue shales and limestones.

Toward the southeast, away from the South Vernon structure, this formation grades into red shales and limestones. Underlying the Wichita-Albany in the vicinity of the South Vernon field is a section of Pennsylvanian rocks approximately 1,400 feet thick, consisting of alternating red and blue shales, limestones, and sandstones. The sandstones and red shales decrease in amount with depth. No effort has been made to identify the recognized Pennsylvanian subdivisions of north-central Texas at this point, although sufficient correlative subsurface work has been done to account for a normal thickness of Cisco (upper Pennsylvanian). The lower 300 feet of Pennsylvanian sediments is essentially limestone, which in turn is underlain by a massive limestone section of Cambro-Ordovician age, known locally as the "Big lime." The only well which has completely penetrated the so-called "Big lime" of this area, drilled into igneous rock. This well is the Barkley and Meadows' Stephens No. 14-A, which encountered igneous material at about 2,900 feet and penetrated it to a depth of 3,007 feet. It is centrally located in the South Vernon pool.

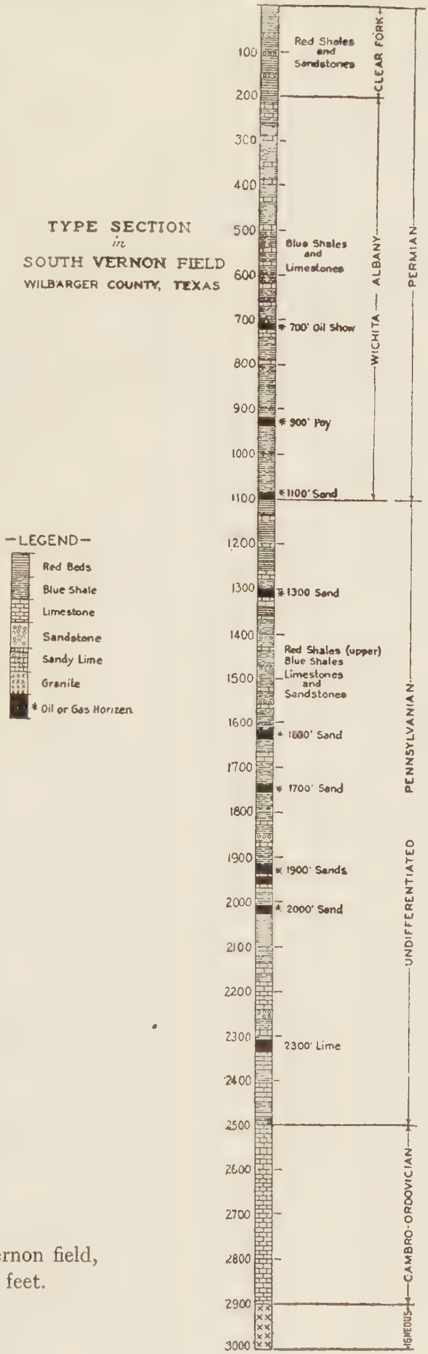


Fig. 1.—Type section in South Vernon field, Wilbarger County, Texas. Scale shown in feet.

REGIONAL STRUCTURE

The major regional feature of the area under discussion and of the counties on the east and west is the Red River uplift, which consists of a chain of dissected Cambro-Ordovician limestone and granite hills, and which extends in a westerly direction from eastern Cooke County to central Foard County, a distance of approximately 200 miles. The axis of this major uplift is almost due east and west along a line extending from the town of Electra to the Roxana Petroleum Corporation *et al.* Matthews No. 1 well in east-central Foard County, which incidentally is the westernmost point of the "Big lime" and granite known to date. All available evidence points to the fact that in Wilbarger County the north flank of the major uplift is much steeper than the south flank.

STRUCTURE

Figure 2 shows the surface structure where workable beds are exposed, and Figure 3 shows the surface structure of the corresponding area.

It will be noticed on the surface detail map that a line separates the surface work done on the Clear Fork sandstones and the work done on the southeast on the Wichita-Albany limestones, and that no effort has been made to tie the two pieces of work together. This expedient was resorted to because of the fact that while a reliable columnar section could be carried in the limestone area, it was found impossible to tie this section to the sandstone section of the Clear Fork, in which the work was done primarily on very short exposures and local dips.

In the work shown on the subsurface map (Fig. 3), the base of what is known locally as the 1,300-foot sand was used as datum for contouring. The sand, as a stratigraphic unit, shows a remarkable persistence throughout the area.

RELATION OF PRODUCTION TO STRUCTURE

On both of the maps accompanying this paper the productive areas are shaded, and a comparative study of the two maps will show at once the general relations of surface structure, subsurface structure, and production. The outstanding feature on these maps, from the standpoints of surface structure, subsurface structure, and production, is the north line of folding with an east-west trend, which represents the axis of the major uplift of the region. Subsidiary to this, and approximately parallel, is the Landreth-Sigler line of folding down the south flank from the axis of the major feature. Along these trends are located the commercial and non-commercial pools enumerated in the history at the beginning of this

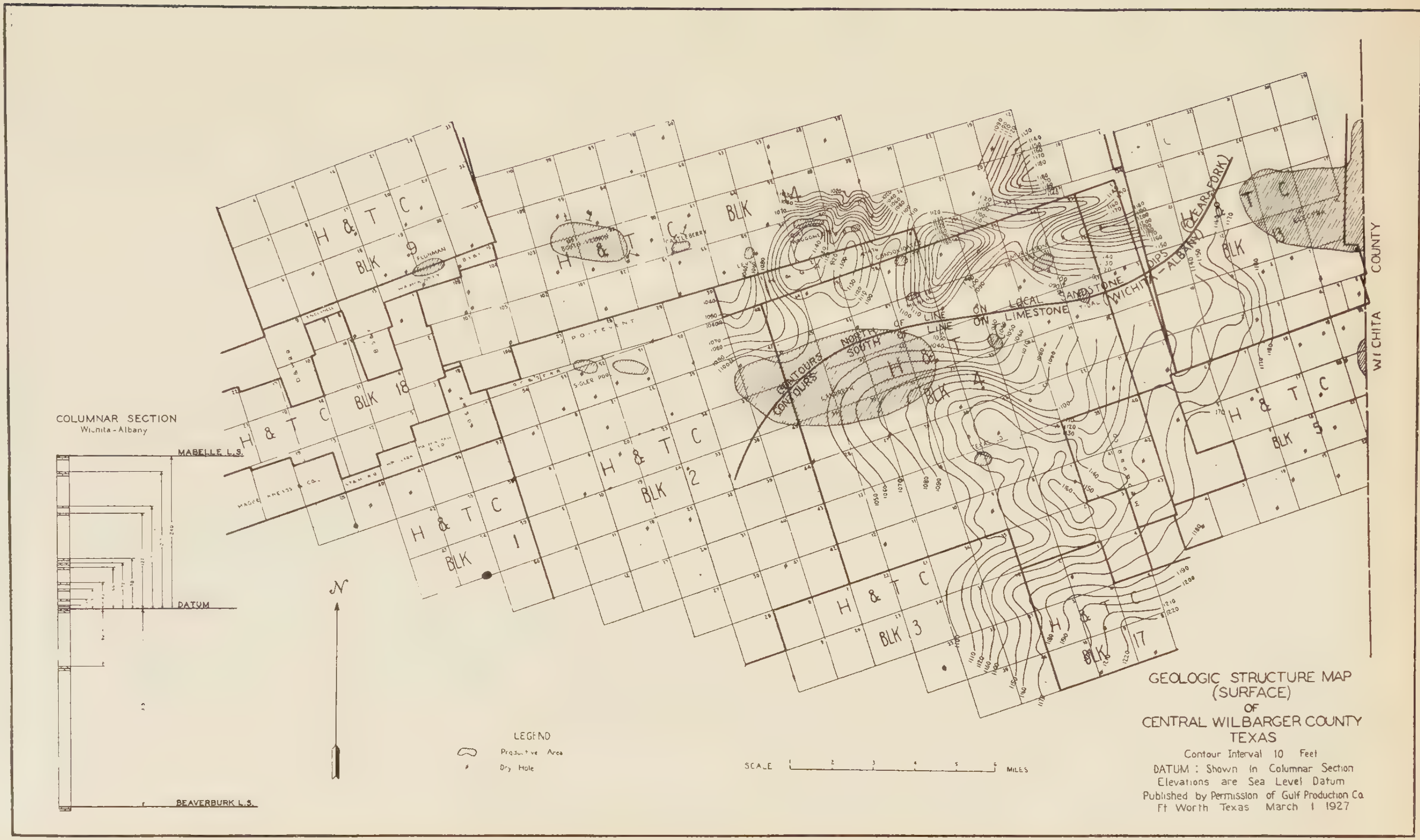
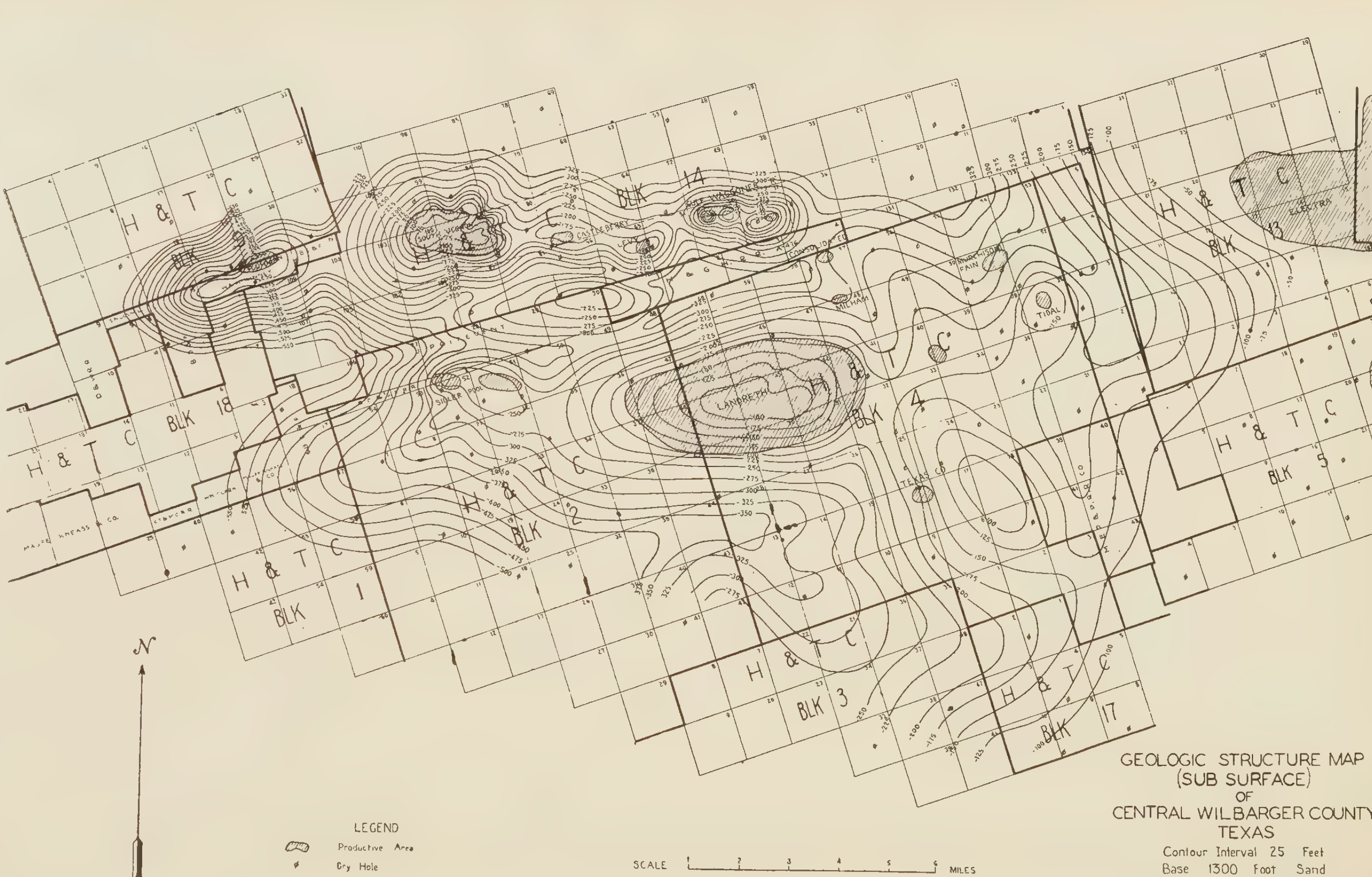


FIG. 2.—Geologic surface structure map of central Wilbarger County, Texas.



GEOLOGIC STRUCTURE MAP
(SUB SURFACE)
OF
CENTRAL WILBARGER COUNTY
TEXAS

Contour Interval 25 Feet
Base 1300 Foot Sand
Elevations. are Sea Level Datum
Published by Permission of Gulf Production Co.
Ft Worth Texas- March 1 1927

paper, and it might be worth while briefly to consider the relation of production to structure on each of these main features.

The Sigler pool, the first to be discovered in this area, is producing from a sand encountered at a depth of about 2,040 feet. This location was staked by Roy Reynolds, a consulting geologist of Fort Worth, Texas, after a careful study of surface conditions. It is axially located down the west plunge of both a surface and a subsurface anticline. Sufficient development has been done to show that the "pay" in this particular pool is very different in character in different wells, as evidenced by dry holes located close to producers. This, rather than lack of folding, is undoubtedly responsible for the erratic and discouraging behavior of the pool.

The South Vernon pool is located on a compound, steeply-dipping subsurface dome directly on the axis of the major structural feature of the area. Surface evidence of the fold consists of north, east, and southeast local sandstone dips. Production is developed in seven distinct sand and lime horizons, only one of which is persistently productive throughout the pool, namely, the 1,300-foot sand, which is used as the datum for contouring throughout the area. One of these horizons, the 900-foot "pay," which is unimportant, is in the Wichita-Albany. The remaining six are scattered through the Pennsylvanian section. The other producing horizons have shown the common inconsistency of Pennsylvanian and Permian "pays" of north-central Texas. Of the "pays" in this field, the two most prolific are the 1,300-foot "pay" and the limestone "pay" encountered at 2,300 feet. Considering the productive area of the pool as a whole, it may be said that the limits of the productive area are directly controlled by structure, and that local failures in individual sands within the area are due either to lenticularity or to lack of porosity.

The next pool in chronological order of discovery, and probably of first rank in order of producing importance, is the Landreth pool, discovered during the year 1925 by the Noble Oil Company *et al.* This pool is located about 80 feet down the northwest plunge of a large surface anticline which has its crest about 4 miles southeast of the Landreth production. This same surface structure, projected on rather meager evidence, extends through the Sigler production discussed in the preceding paragraph. This surface structure is reflected underground by a compound anticline with axis approximately coinciding with the surface fold. As in the South Vernon pool, approximately seven "pays" are present. The most prolific and consistent of these is the 1,800-foot "pay." The 1,300-foot "pay," used as datum in all of this work, is gen-

erally present throughout the pool, but in most places is non-productive. The limits of the producing area, considering all horizons together, are as closely controlled by subsurface structure as in the South Vernon pool, and also as in that pool, the productivity of any individual stratum is controlled by porosity.

While discussing the Landreth pool, it is of interest to note that recently The Texas Company *et al.* have developed a small amount of production near the apex of the surface structure, in Secs. 16 and 17, H. & T. C. R. R. Survey, Block 4. On subsurface structure this production occupies a position on the west flank of the easternmost of the domes of the compound feature.

Next in order of development and of only secondary importance as a producer, although very significant as to structure, is the small pool in Sec. 50, H. &. T. C. R. R. Survey, Block 14, discovered by the Gulf Production Company. "Pays" in this pool have proved to be even more erratic than in the average pool in Wilbarger County, and it is doubtful if it should be considered of commercial value. However, its significance in this paper lies in the fact that it is situated directly on the axis of the major uplift of the area, and that its production is in direct conformity with both surface and subsurface structure. Its structural position is almost identical with the South Vernon pool both as to elevation and as to trend, and it is believed that the failure of the pool to reach commercial proportions is due principally to the extreme steepness of the folding.

The Fluhman pool, located 2½ miles due west of the South Vernon pool, lies in an area where all surface exposures are hidden by unconsolidated sediments probably of recent age. Absolutely no surface evidence of structure is to be found. This pool was located solely on subsurface data, and the discovery well was drilled by the Murchison & Fain Oil Company in October, 1926. Although the productive area will probably not exceed 100 acres in extent, the wells have proved to be very consistent producers. A second producing horizon has already been developed, and it is probable that ultimately several additional "pays" will be discovered as deeper drilling is carried on. Production in this small pool is very closely controlled by subsurface structure.

In addition to the pools previously discussed, a few isolated producing wells have been developed which are indicated on the attached maps, but which seem to be of so little importance that they do not justify discussion.

ECONOMIC IMPORTANCE

Although somewhat irrelevant to the title of this paper, it might be of interest to consider briefly the economic value of Wilbarger County production. Aside from the production in Wilbarger County associated directly with the Electra field, figures upon which are not available, the county has produced approximately 9,000,000 barrels to January 1, 1927, and from its present behavior it is estimated that it will produce approximately 4,000,000 barrels during 1927.

In order to attempt any estimates as to the ultimate yield of properties in this county it was found necessary to base figures on the South Vernon pool, which has an areal extent of 675 acres, all fairly well developed, and past its peak of production. This pool has produced by years as follows:

	Barrels
1924	306,381
1925	2,926,643
1926	1,994,251
1927	1,000,000 (partly estimated)

A decline curve based on these figures and produced to estimated exhaustion for the field is shown in Figure 4. From this curve it is estimated that the ultimate yield of the South Vernon pool will be 8,761,000 barrels, and that its average yield per acre will be 13,000 barrels.

Whether or not the Landreth pool and other minor pools in the county will show this yield per acre is a matter of conjecture, but even though Landreth fails to reach this per-acre figure, it is nevertheless certain that, because of its much greater area, the pool as a whole will greatly exceed the ultimate yield of the South Vernon pool.

The producing horizons and the well action in the Landreth pool and other pools in this part of the county compare very favorably with the production in the South Electra pools on the east, which are generally conceded an ultimate yield of about 8,000 barrels per acre, and the writers of this paper are rather inclined to believe that Landreth and a majority of the smaller Wilbarger County pools will come nearer to this figure than to the South Vernon figure.

CONCLUSIONS

In general, there is a marked relation throughout central Wilbarger County between surface structure and subsurface structure, and between folds and production, the relation being much closer between subsurface folds and production than between surface folds and production.

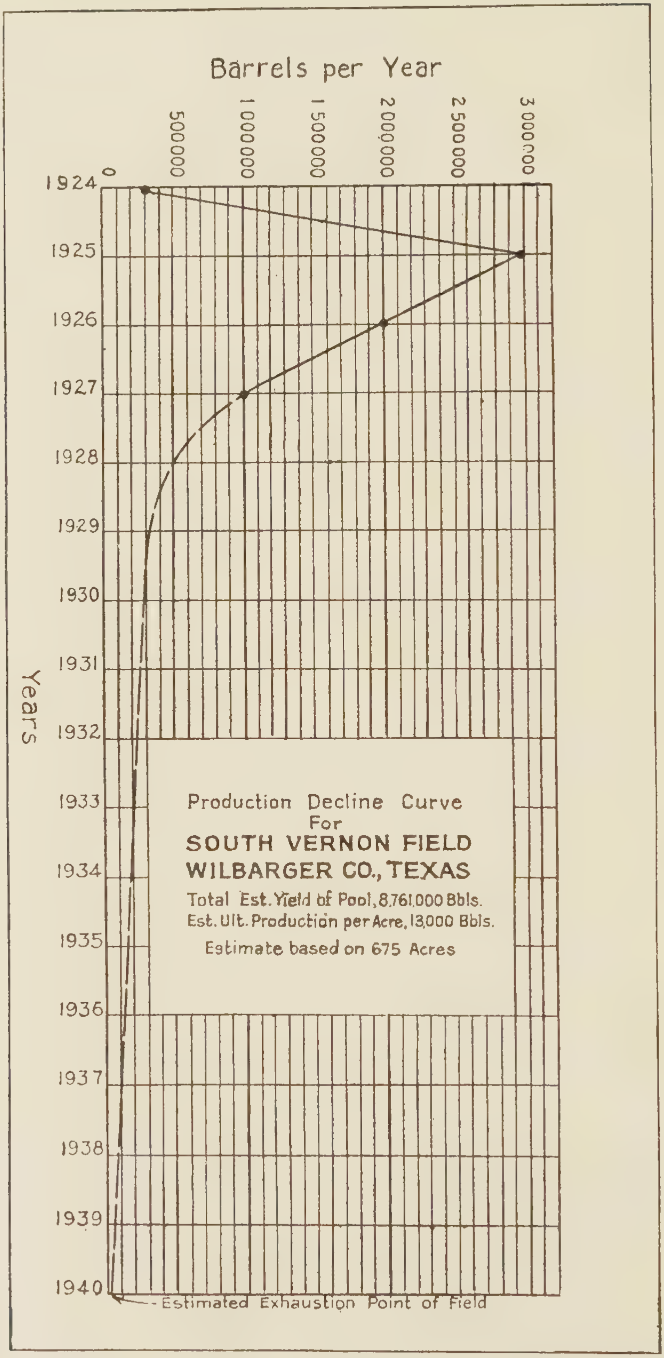


FIG. 4.—Production decline curve for South Vernon field, Wilbarger County.

Surface and subsurface folds in this area have a common axis, but dips in the subsurface beds are considerably more accentuated than those in the surface formations, due principally to convergence of the section toward folds.

It is estimated that the ultimate yield of the South Vernon pool will be approximately 13,000 barrels per acre, and that the yields of the other pools of Wilbarger County will range from this figure to 8,000 barrels per acre, the generally accepted recovery for the South Electra pools on the east.

OIL AND GAS FIELDS OF THE MEXIA AND TEHUACANA FAULT ZONES, TEXAS[1]

FREDERIC H. LAHEE[2]
Dallas, Texas

ABSTRACT

The Mexia fault zone is a series of overlapping faults, all trending in a direction a little oblique to the trend of the zone as a whole. All have a downthrow on the west, or on the side up the regional dip of the strata. This series of faults passes through Milam, Falls, Limestone, Freestone, Navarro, Henderson, and Kaufman counties. In Limestone, Freestone, and Navarro counties eight oil and gas pools have been discovered associated with major faults in this zone. From the south northward these are the South Groesbeck, North Groesbeck, Mexia, Wortham, Currie, North Currie, Richland, and Powell fields. Three or four miles west of the Mexia fault zone is another parallel series of faults, the Tehuacana zone, in which there are now two oil fields (Nigger Creek and Cedar Creek).

All these ten fields yield their principal production from the Woodbine sand. Up to December 31, 1927, 212,544,366 barrels had been produced from the ten pools, or about 28,300 barrels per acre.

Evidence points to the conclusion (1) that the faulting occurred partly in post-Cretaceous, pre-Midway time and partly in post-Wilcox time; (2) that the oil had its source in the Eagle Ford shale or in shales in the Woodbine formation, or in both; (3) that it came into its present reservoirs after faulting; and (4) that it reached its present position by lateral migration rather than by migration up the faults from a deep source.

INTRODUCTION

Acknowledgments.—For many courtesies and for helpful criticism and discussion of certain phases of this report the writer owes grateful acknowledgment to R. A. Liddle, R. B. Whitehead, H. B. Hill, C. E. Sutton, N. L. Thomas, E. B. Stiles, H. J. McLellan, and Earl A. Trager. To F. G. Clapp and the Lone Star Gas Company he is indebted for the use of Figure 3; to Wallace E. Pratt, for the contour map employed as a base for Figure 15; to H. B. Hill and the U. S. Bureau of Mines, for the contoured base map of Figure 23; and to F. Julius Fohs, Heath M. Robinson, and W. A. Reiter, for the right to publish Figure 6. Considerable assistance was given by J. A. Waters in paleontological determinations and by W. E. Winn in chemical analyses and interpretations.

[1] Read before the Association at the Tulsa meeting, March 25, 1927. As far as possible the information has been brought up to date of April, 1928. Manuscript received by the editor, May 11, 1928.

[2] Chief geologist, Sun Oil Company.

Location and relations to other structural features.—Geologically nearly all of East Texas is situated within an arm of the Gulf embayment. This arm is called the East Texas geosyncline. It is partially closed on the northeast by the Sabine uplift,[3] and on the west it is limited by the Balcones fault zone, which is several miles east of a line connecting the Ouachita Mountains of southeastern Oklahoma and the Llano-Burnet uplift, or Central Mineral Region, of central Texas (Fig. 1).

The Balcones fault zone[2] passes through McLennan, Bell, Williamson, Travis, Hays, and Comal counties, thence turns more nearly westward through Bexar, Medina, and Uvalde counties. The width of this zone ranges from 2 to 5 miles. It includes a complex series of faults most of which are nearly parallel with the zone itself, within which they lie. Their aggregate displacement is down on the east and south, although locally some of them show a downthrow on the northwest side. The total displacement amounts to as much as 800 or 1,000 feet in Travis and Hays counties, but northward from Travis County and southwestward from Hays County the throw decreases. In McLennan County, Lula Pace[1] states that the throw is between 200 and 400 feet. Here the zone becomes "an anticline faulted in various places, extending almost north and south across the county."[4] Still farther north the faulting is difficult to trace on account of the soil cover. The Balcones zone is thought to extend through Hill, Ellis, and Dallas counties.

From 25 to 35 miles east of the Balcones fault zone is the Mexia fault zone (Fig. 1), which came into recognition after the discovery of oil in the Woodbine sand on the Mexia structure in Limestone County. The Mexia zone, like the Balcones zone, consists of a group of subparallel faults, all of which trend nearly parallel with the faulted belt of country

[1] Sidney Powers, "The Sabine Uplift," *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 4, No. 2, 1920.

[2] R. T. Hill and T. W. Vaughan, "Geology of the Edwards Plateau and Rio Grande Plain," *U. S. Geol. Survey Ann. Rept. 18* (1896–97), Pl. 2, pp. 193–321. R. A. Liddle, "Geology and Mineral Resources of Medina County," *University of Texas Bull. 1860* (October 25, 1918). T. Wayland Vaughan, "Uvalde Folio," *U. S. Geol. Survey Folio 64* (1900). R. T. Hill and T. W. Vaughan, "Austin Folio," *U. S. Geol. Survey Folio 76* (1902). Lula Pace, "Geology of McLennan County, Texas," *Baylor Bull. XXIV*, No. 1 (January, 1921). W. E. Pratt and F. H. Lahee, "Faulting and Petroleum Accumulation at Mexia, Texas," *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 7, No. 3 (May–June, 1923), pp. 226–36. F. J. Fohs and H. M. Robinson, "Structural and Stratigraphic Data of Northeast Texas," *Econ. Geol.*, Vol. 18, No. 8 (December, 1923), pp. 709–31.

[3] Lula Pace, *op. cit.*, p. 17.

[4] *Ibid.*, p. 16.

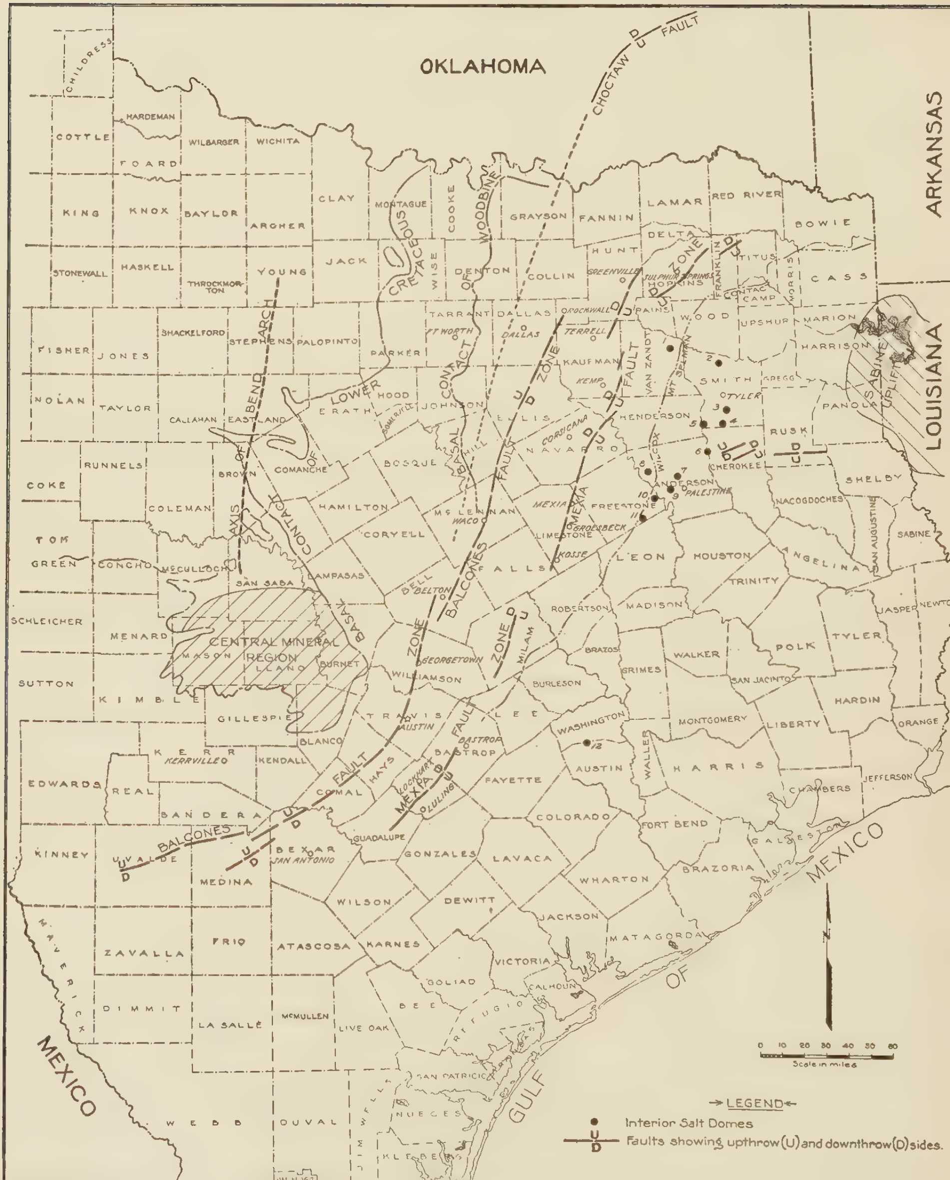


FIG. 1.—Index map showing major structural features of East Texas, north of the Gulf Coast d
trict. Notice that the Mexia fault zone is 30 or 40 miles east of the Balcones fault zone. The interi
salt domes are numbered as follows: (1) Grand Saline, (2) Steen, (3) Whitehouse, (4) Bullard, (
Brooks, (6) Boggy Creek, (7) Keechi, (8) Bethel, (9) Palestine, (10) Butler, (11) Oakwood, (1
Brenham.

in which they are situated; but in the Mexia zone the downthrow is on the west. The total displacements of the several major faults range from 250 to more than 600 feet.

Between these two principal zones of faulting, the western with downthrow on the east, and the eastern with downthrow on the west, is a *graben* which is broken by many other faults, most of them less extensive, some with eastward downthrow and some with westward downthrow.

This paper is concerned chiefly with the eight producing structures which are situated in the Mexia zone in Limestone, Freestone, and Navarro counties, Texas (Fig. 2). References will be made also to the Nigger Creek and Cedar Creek structures in a zone of faulting a few miles west of the Mexia zone. In treating this subject under the several major headings the writer has followed the order of discovery of the several pools.

HISTORY

Mexia-Groesbeck district.—According to George C. Matson,[1] the first drilling in the Mexia district was done by the Mexia Oil and Gas Company, which drilled ten wells before a successful gasser was finally completed in 1912. By the end of 1913, fifteen or sixteen producing gas wells had been completed, and more than thirty were completed in 1914.

In 1915 both G. C. Matson and Frederick G. Clapp were engaged in mapping the Mexia-Groesbeck area. The results of their work were very similar. Clapp's report was written for the Lone Star Gas Company. Matson's report was published the following year (1916) in *Bulletin 629* of the U.S. Geological Survey. With the kind permission of the author and the Lone Star Gas Company the writer has reproduced the essential features of Clapp's map in Figure 3.

Referring to the possibility of finding petroleum below the main gas "pay" (Nacatoch sand) at Mexia, Matson, in 1916, wrote as follows:

> If a well drilled to test the lower sands should prove unsuccessful above the Austin chalk, it might be well to continue to these deeper sands (Woodbine) in order to determine whether they are oil- or gas-bearing in the Mexia-Groesbeck field. In spite of the fact that these beds contain potable water at Corsicana, it is worth while to test them for oil and gas in the Mexia-Groesbeck field, where the structure is exceptionally favorable for the accumulation of oil and gas. The best place to locate a well to test the deep sands in the Mexia-Groesbeck field would be where the upper gas sand is high.[2]

[1] G. C. Matson, "Gas Prospects South and Southeast of Dallas," *U.S. Geol. Survey Bull. 629* (1916), p. 88.

[2] *Ibid.*, p. 104.

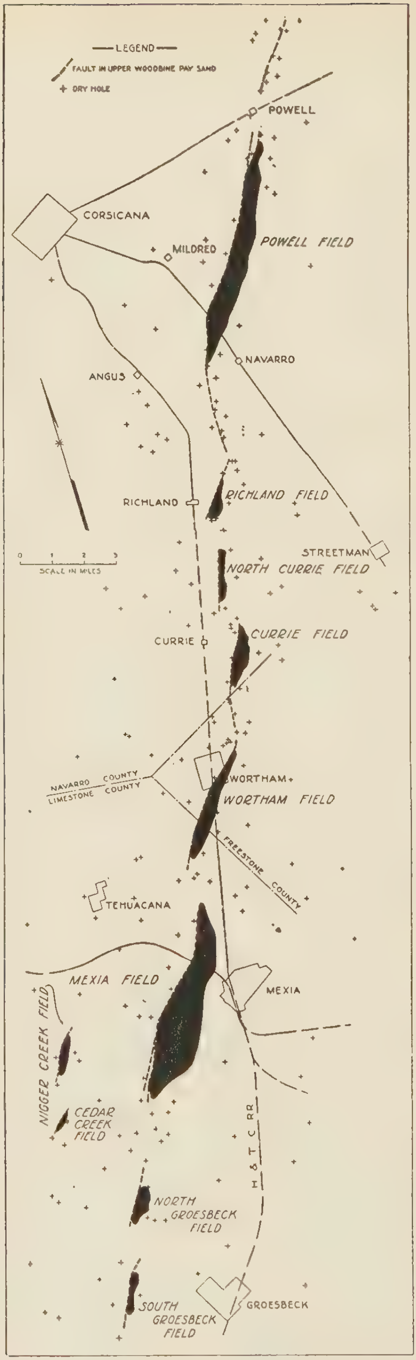


FIG. 2

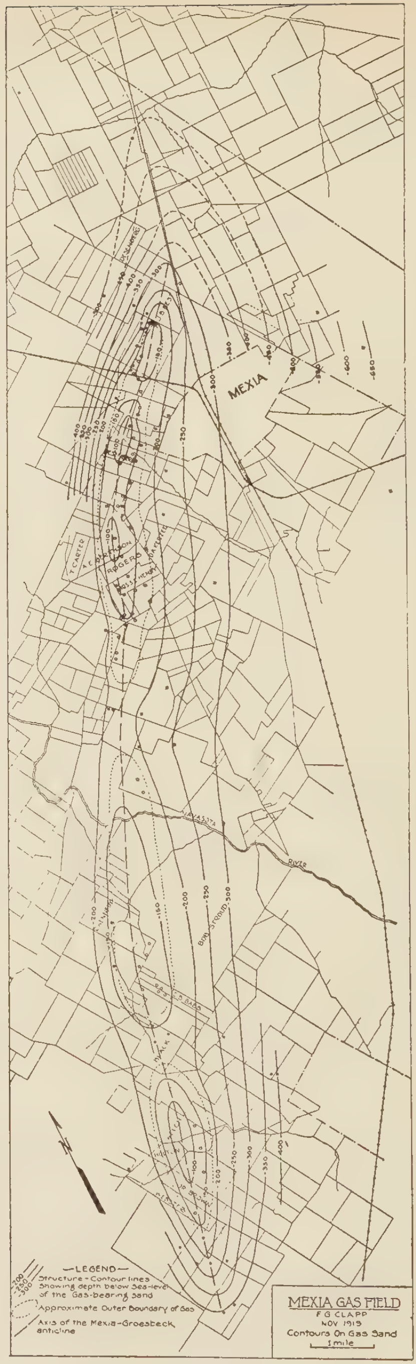


FIG. 3

FIG. 2.—Outline map of the oil and gas fields in the Mexia and Tehuacana fault zones. The latter includes the Nigger Creek and Cedar Creek fields. The crosses mark the locations of dry holes nearly all of which tested the Woodbine sand (see p. 359).

FIG. 3.—Copy of the essential features of F. G. Clapp's original map of the Mexia and Groesbeck structures, prepared in 1915. Published with permission of the Lone Star Gas Company and F. G. Clapp.

A few years later the Mexia Oil and Gas Company commenced a well on the L. W. Rogers tract, and carried it down to a depth of 1,800 feet. At this depth, with the advice of F. Julius Fohs, this well was taken over by the late Col. A. E. Humphreys, and, for a substantial interest in the holdings of the Mexia Oil and Gas Company, was drilled to a depth of more than 3,100 feet into the Woodbine sand. In October, 1920, this Rogers No. 1, the discovery well of the Woodbine "pay" in the Mexia field, was completed as a pumper making about 150 barrels of oil per day, with 35 barrels of water.

The second well, offsetting the discovery well, was Tom Berthelson No. 1, drilled by the Humphreys Company and completed in the summer of 1921 with an initial production of 4,000 barrels. By August, 1921, there were ten or twelve producing wells, but these were for the most part pinched in because of inadequate storage and transportation facilities.

These first wells were located with reference to the subsurface structure of the Nacatoch gas sand (Fig. 3), and what land was available for trading was bought and sold on the basis of this structure. In 1914 Alexander Deussen had written as follows:

> A fault of small throw crosses the country in a northeast-southwest direction. This fault has broken the continuity of some of the sand lenses that occur in the Navarro formation of the Cretaceous, and it is probable that the gas in the Mexia district is found in these discontinuous and locally warped sands on the east side of the fault.[1]

However, not until after the drilling of a dozen or more wells to the Woodbine sand did geologists begin to realize the importance of the faulting associated with the structure. As a matter of fact, a correct understanding of the nature of this faulting was probably not reached until after the principal campaign of lease trading had been finished.

Following the activities of leasing and development in the main part of the field, interest shifted to the so-called Fish Pond area, that is, the northern end of the field, north of the Texas and Brazos Valley Railroad (Fig. 4).

In August, 1922, the Humphreys-Mexia Company, in deepening its Kollman No. 9, found the lower Woodbine "pay," called the "Kollman pay," at 3,193 feet, about 280 feet below the top of the Woodbine formation.

[1] Alexander Deussen, "Geology and Underground Waters of the Southeastern Part of the Texas Coastal Plain," *U. S. Geol. Survey Water-Supply Paper 335* (1914), p. 301.

FIG. 4.—Lease and well map of the Mexia field. The depths of wells drilled below the main pay are indicated. The cross-hatched areas labeled *K* include wells producing from the Kollman "pay." The discovery well and second well of the field are marked as such (see Fig. 15).

Although at first the drilling campaign at Mexia was rapid, the larger number of the leases, having been held by the Humphreys-Mexia Company and later sold to the Pure Oil Company, have been developed systematically and rationally.

The monthly peak of production was reached in January, 1922, when 5,078,069 barrels were produced by about 300 wells. The daily peak of 176,001 barrels was reached on February 12, 1922. Figures for production are given in Table I.

About the end of October, 1926, E. L. Smith spudded in the Jake Steubenrauch No. 1, with the intention of drilling to the Trinity sand.

TABLE I

Production Figures for the Mexia Pool (in Barrels)

Date	Month's Production	Total Production for Year	Total Production to End of Year Mentioned
October, 1921	428,379	...	...
December, 1921	3,562,280	5,783,236	5,783,236
December, 1922	1,841,211	33,937,513	39,720,749
December, 1923	1,161,903	18,044,375	57,765,124
December, 1924	624,516	10,466,567	68,231,691
December, 1925	467,490	6,700,444	74,932,135
December, 1926	357,111	4,769,732	79,701,867
December, 1927	...	3,622,385	83,324,252

In June, 1927, this well blew in for 10,000,000 cubic feet of wet gas at a depth of 5,732 feet.

The Groesbeck district, south of Navasota River, was mapped by Clapp and also by Matson as part of the Mexia anticline in the Nacatoch gas sand. The first deep holes here, like those at Mexia, were drilled on the basis of the gas rock structure (Fig. 3). In July, 1921, the Humphreys Company, in its Welch No. 1, found salt water in the Woodbine sand at 3,026 feet. This was abandoned as a dry hole at 4,365 feet in October, 1921. The Texas Company's Stroud No. 1 was abandoned at 4,486 feet in March, 1922. The first well to give any encouragement to further drilling was the Texas and Pacific Coal Company's Browder No. 1, which, in October, 1922, encountered 15,000,000 cubic feet of gas per day in the Woodbine at 3,000 feet.

Careful geological work on the surface and subsurface correlation of the logs of wells drilled to the Woodbine or deeper have proved that there are at least two distinct structures at Groesbeck, and that these are entirely separate from the Mexia structure. The North Groesbeck and South

Groesbeck structures are small and unimportant. The wells on these structures, with two exceptions, yield gas from the Woodbine formation. These two exceptions, the Pure Oil Company's Stockton wells, No. 1 and No. 2, yield a little high-gravity oil.

The Currie field.—Several shallow wells, some producing a little oil and some a little gas, had been drilled near the town of Currie prior to the development which led to the discovery of the Currie fault and the associated accumulation of oil in the Woodbine sand; but none of these shallow wells was on the main Currie structure. The discovery well of the Woodbine "pay" was Meador No. 1, drilled by the Humphreys-Mexia Company and completed with an initial daily yield of about 400 barrels in October, 1921. The second oil well was the Humphreys-Mexia Company's English No. 1, with an initial production of 900 barrels, completed March 23, 1922. Just before this, on March 19, 1922, the Homa-Okla Company completed its McGraw No. 1 as a 25,000,000-cubic foot gasser.

As may be seen on Figure 5, Meador No. 1 is almost at the extreme northern end of the Currie field. Credit for the location is due to F. J. Fohs, W. A. Reiter, and H. M. Robinson, of the Humphreys-Mexia Company. It is an interesting fact, however, that this location was selected near the crest of a supposed essentially unbroken surface anticline (Fig. 6), for, as in the case of Mexia, early geological field work failed to reveal the importance of the major fault. Evidences of this fault at the surface are almost entirely masked by soil and long even slopes of plowed land and pasture.

The first Woodbine production found at Currie came from the upper 50 or 75 feet of the Woodbine formation. In April, 1923, a deep pay sand was discovered by J. K. Hughes in his Morrow No. 1, at the southwest edge of the field. This well made an initial yield of 5,000 barrels of oil per day from a sand now called the "Morrow sand," 300 feet below the top of the Woodbine formation and 250 feet below the main upper Woodbine pay sand.

The production of the Currie field has been relatively small. The monthly peak of production was 358,995 barrels, in July, 1922. Production figures are given in Table II.

North Currie field.—The discovery well of the North Currie field was drilled by Seay and Cranfill on the West land. Location for this well was chosen on recommendations made by D. J. Edson, of the Humble Oil Company, and F. H. Lahee, of the Sun Oil Company. The position of the outcrop of the major fault was not known. The recommendations were based on general trend of the fault zone and on suggestive topog-

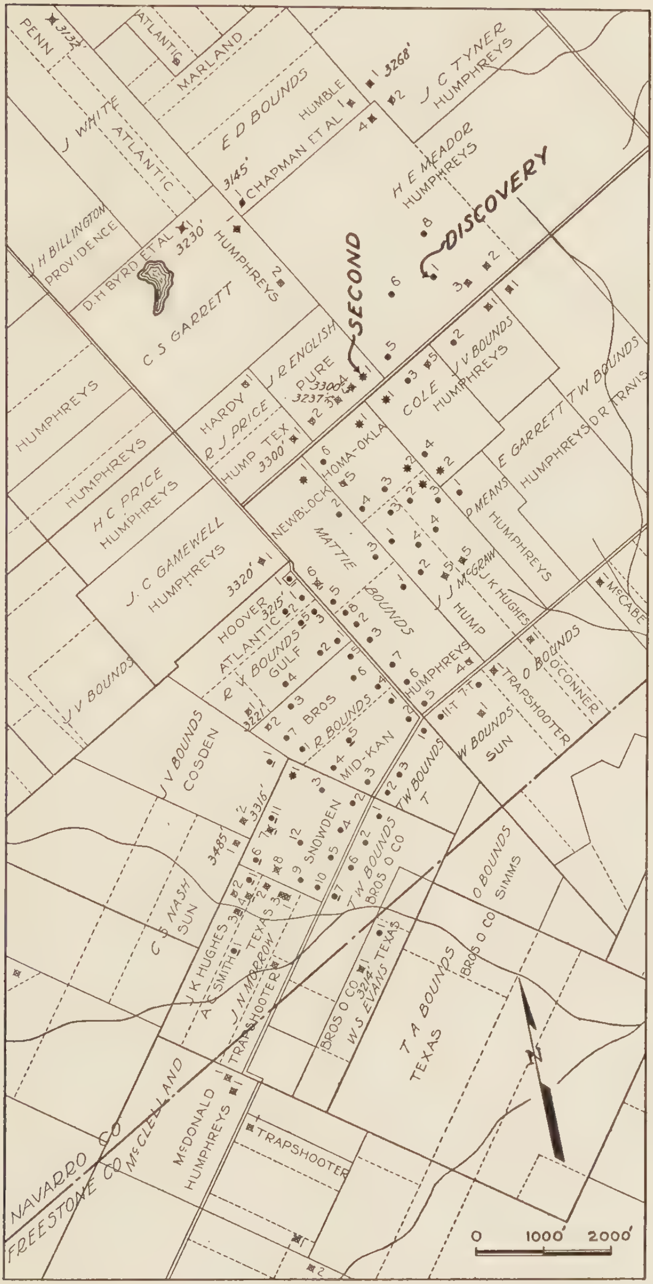


FIG. 5.—Lease and well map of the Currie field. The underscored wells were drilled into the Morrow "pay." The discovery well and second well are indicated. Depths of wells drilled below the main "pay" are shown (see Fig. 18). Scale in feet.

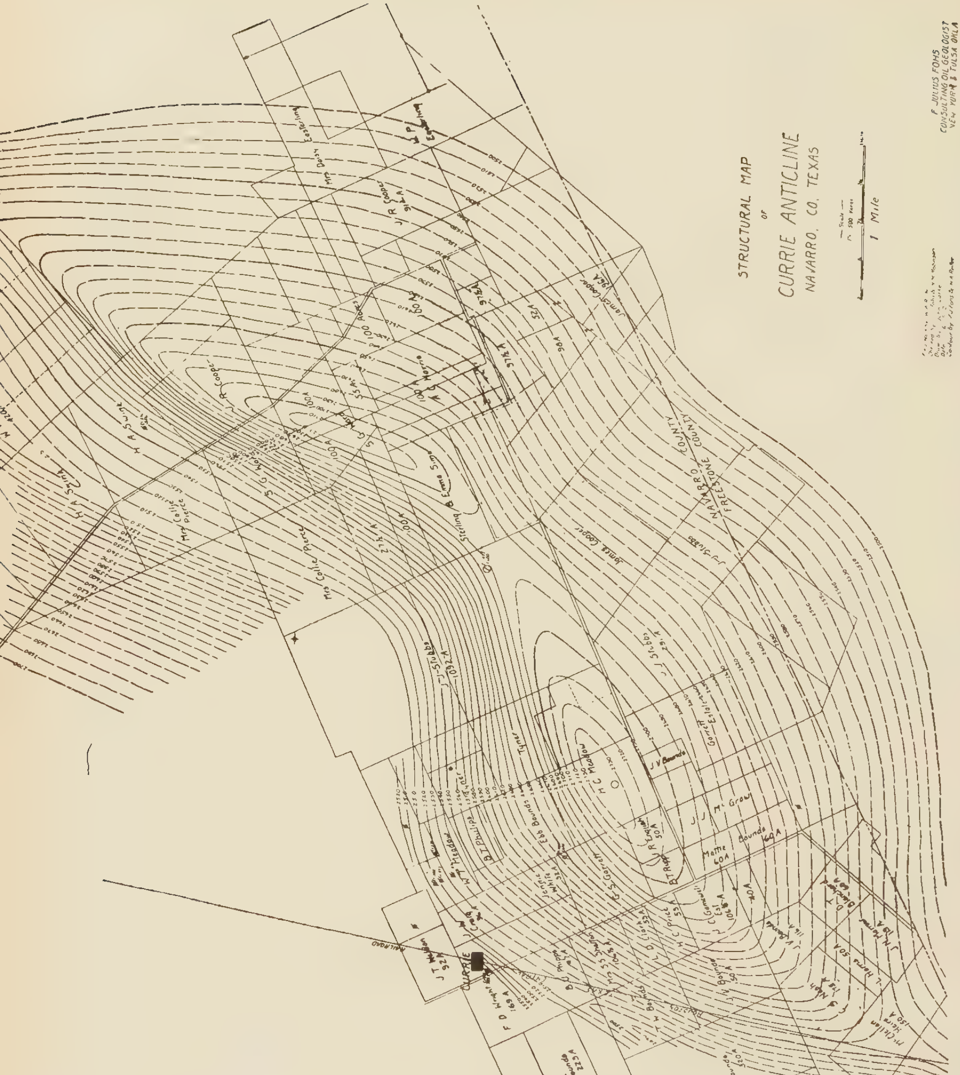


FIG. 6.—Surface geology of the area of the Currie field as originally mapped by W. A. Reiter and checked by F. Julius Fohs and H. M. Robinson. The discovery well of the Currie field was drilled on top of the southwest closure.

raphy. The well was completed for 60,000,000 cubic feet of gas per day in January, 1922, after deepening to 2,996 feet from 2,976 feet, where it produced 20,000,000 cubic feet early in December, 1921. Several other gas wells were drilled in this area in 1922, the first oil well being the Sun Oil Company's C. S. West No. B1, which came in making 850 barrels at 2,987 feet in August, 1922.

After a lapse of two years the Sun Oil Company's H. A. Swink No. A1 was brought in for 13,000,000 cubic feet in November, 1924, thus extending the field southward and, with the subsequent completion of this company's Ernest Swink No. A1, Ernest Swink No. B1, and Swink-Wilson No. 1, all gassers, paving the way to the discovery of the small oil-producing area at the southeast end of the structure. The first oil well here

TABLE II

PRODUCTION FIGURES FOR THE CURRIE POOL (IN BARRELS)

Date	Month's Production	Total Production for Year	Total Production for Field to End of Year
November, 1921	1,576	....	....
December, 1921	7,329	8,905	8,905
December, 1922	184,821	2,005,012	2,013,917
December, 1923	105,983	1,741,774	3,755,691
December, 1924	58,077	981,921	4,737,612
December, 1925	28,301	470,717	5,208,329
December, 1926	26,439	335,098	5,543,427
December, 1927	....	249,048	5,892,475

was Barclay and Meadows' Hilburn No. 1, completed for 200 barrels plus 2,000,000 cubic feet of gas about the middle of June, 1925 (Fig. 7).

Up to this time all the gas and oil produced from the Woodbine formation in this field had come from two "pays," one 30–35 feet, and the other 50–55 feet, below the top of the Woodbine formation. The latter is known as the "main pay" or the "big gas pay." In November, 1925, after drilling to 3,184 feet in the H. A. Swink No. A1, then plugging back by stages to 3,022 feet, the Sun Company discovered the "Swink pay" 35 feet below the "main pay," or 85–90 feet below the top of the Woodbine formation. This sand has produced as high an initial yield as 500 barrels daily in two wells subsequently deepened (the Gulf Company's Hilburn No. 1 and the Sun Oil Company's E. Swink No. A2).

Several wells have been deepened to the Morrow pay zone, first penetrated by Barclay and Meadows in their Hilburn No. 3, but none of these has made a commercial well.

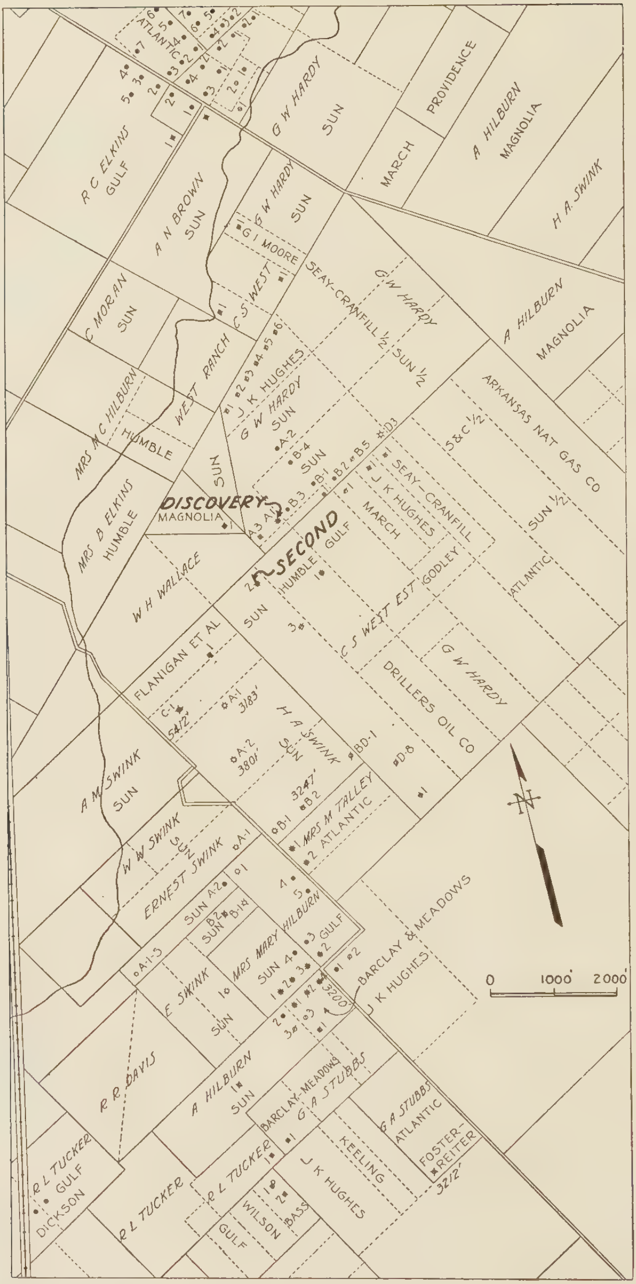


FIG. 7.—Lease and well map of the North Currie field. The discovery well and second well are shown; also the depths of wells that were carried below the main "pay" (see Fig. 20). Scale in feet.

The monthly peak of oil production for the northern end of the structure was 3,952 barrels in April, 1923. After the discovery of oil at the south end of the structure, a peak yield of 21,179 barrels was reached in August, 1925. A considerable quantity of gas has been taken from this pool by the Lone Star Gas Company. The oil production record for this field is shown in Table III.

Three-fourths of a mile southwest of the south end of the pool Dickson has drilled several shallow holes which produce a little oil from the basal Midway sand at depths ranging from 360 to 370 feet.

In the north end of the field two holes (Seay-Cranfill and Atlantic's West No. 1, and Sun Oil Company's West No. D1) found gas at an approximate depth of 600 feet, this gas coming from the Nacatoch sand horizon on the upthrown side of the fault.

TABLE III

PRODUCTION FIGURES FOR THE NORTH CURRIE POOL (IN BARRELS)

Date	Month's Production	Total Production for Year	Total Production for Field to End of Year
To December 31, 1924	....	....	77,184
December, 1925	5,562	76,547	153,731
December, 1926	6,349	82,307	236,038
December, 1927	....	41,813	277,851

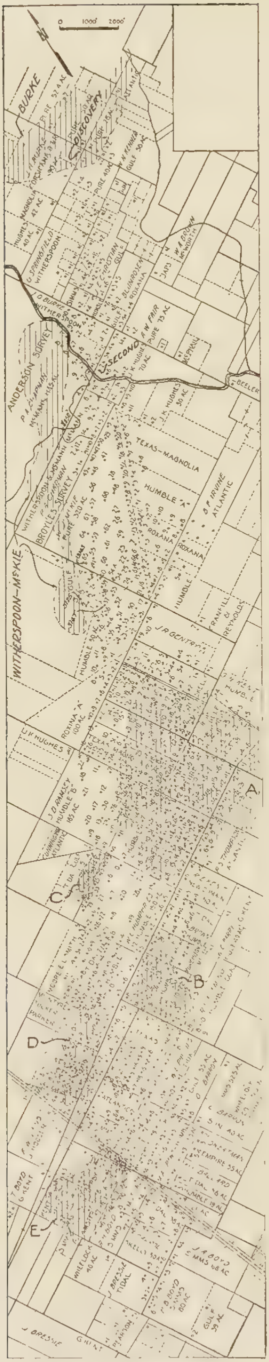
In August, 1926, the Sun Oil Company commenced drilling on its H. A. Swink No. C1. This was the first well in the Mexia zone located west of the Woodbine fault trace with the object of testing the Trinity sand. Unfortunately it never reached the Trinity. It had good showings at 4,843, 5,170, and 5,268 feet, all in the Glen Rose, and was finally junked and abandoned in the Glen Rose at a total depth of 5,415 feet.

The Powell field.—The Powell field as now developed includes parts of two of the old shallow pools of the Corsicana district, namely, the Witherspoon-McKie pool and the Burke pool (Fig. 8).

In the former the highest productive sand ranged in depth from 825 to 875 feet, and the lower sand was 100 feet deeper. Oil and gas were present only on the crest of the structure. Gas occurred in both sands, but was more plentiful in the lower.

The Burke pool, 1 mile south of the town of Powell, was situated, according to Matson,[1] on a very pronounced anticlinal nose, plunging

[1] G. C. Matson and O. B. Hopkins, "The Corsicana Oil and Gas Field, Texas," *U.S. Geol. Survey Bull. 661* (1917), pp. 211–52.



steeply southwestward. The oil in the upper part of this structure was found from 400 feet to 480 feet below sea-level, in the upper beds of the Nacatoch sand zone.

On the southwest end of the Burke anticline, near the south edge of the old Burke shallow pool, was located the well which finally reached oil in the Woodbine sand. This was the J. H. Burke No. 1, drilled by the Corsicana Deep Well Company, and, after about 3 years consumed in its drilling, completed on January 8, 1923, with an initial yield of 400 barrels from a depth of 2,963 feet. Salt water appeared in this well within 30 days after its completion.

On May 8, 1923, the J. K. Hughes Development Company penetrated the Woodbine sand at 2,841 feet in its McKie No. 1, located just east of the northeast end of the Witherspoon-McKie shallow pool, $1\frac{1}{2}$ miles southwest of the Burke discovery well. The McKie well commenced flowing 8,000 barrels daily from a very few feet of sand. Following this an exceedingly intense development campaign resulted. By November, 1923, the Powell field had been practically drilled up. The peak of production was reached in that month: 8,116,065 barrels from 513 wells. The daily peak yield was 356,000 barrels, on November 14, which declined to 90,000 barrels by December 15.

Since 1923 production at levels above the Woodbine "pay" has been discovered in several parts of the Powell field.

FIG. 8.—Lease and well map of the Powell field. The discovery well and second well are indicated; also the depths of wells drilled below the main "pay." The cross-hatched areas include wells producing from pay sands above the Woodbine formation. The Burke and Witherspoon-McKie shallow pools antedated the discovery of oil in the Woodbine. Pools *A*, *B*, *C*, *D*, and *E* are mentioned in the text (see also Fig. 23). Scale in feet.

Production figures for the Powell field are given in Table IV. These include oil from the shallow sands developed since 1923.

TABLE IV

PRODUCTION FIGURES FOR THE POWELL FIELD (IN BARRELS)

Date	Month's Production	Total Production for Year	Total Production for Field to End of Year
April and May, 1923	478,292	....	....
December, 1923	2,896,222	30,373,335	30,373,335
December, 1924	1,848,896	32,935,899	63,309,234
December, 1925	1,095,625	17,176,938	80,486,172
December, 1926	624,323	10,022,324	90,508,496
December, 1927	....	5,839,114	96,348,610

The Richland field.—In November, 1923, McDonald Brothers obtained some oil and water from the Woodbine sand in their A. N. Brown No. 1, which was completed as a good pumper in February, 1924 (Fig. 9). This well was located along the general trend between Powell and North Currie. The second well, the Sun Oil Company's W. P. Brown No. 1, 4,500 feet, somewhat south of west of McDonald Brothers' well, was completed as a 325-barrel pumper in April, 1924. The peak monthly production was reached in September, 1924, when 679,162 barrels were produced from 75 wells. The figures for production up to December 31, 1926, are given in Table V.

TABLE V

PRODUCTION FIGURES FOR THE RICHLAND POOL (IN BARRELS)

Date	Month's Production	Total Production for Year	Total Production for Field to End of Year
December, 1924	399,192	3,341,714	3,341,714
December, 1925	67,650	1,725,028	5,066,742
December, 1926	29,508	504,782	5,571,524
December, 1927	....	272,576	5,844,100

No shallow oil and no deep oil have been found yet in the Richland field, nor, as far as we know, have any efforts been made to look for such oil (November, 1927).

Wortham.—In May, 1912, a well was completed in a sand at 1,260–80 feet, within the limits of the town of Wortham. This well produced a large flow of gas and enough oil to stain buildings several hundred feet distant. It caused a little excitement, leading to the drilling of twenty

FIG. 9.—Lease and well map of the Richland field (see Fig. 25). Scale in feet.

or thirty other shallow wells, some of which yielded some oil and gas, but none of which was to be compared with the first well. This shallow drilling was finally abandoned.

Not long after the discovery of the Mexia and Currie pools, an outcrop of the fault, which is now known to control the Woodbine oil accumulation in the Wortham field, was found along a south branch of Tehuacana Creek, a little west of the railroad (Fig. 10). Just east of this fault exposure the Humble Company, in March, 1922, finished a dry hole at a depth of 3,120 feet. This hole was too far east of the fault in the Woodbine sand, and too low on the south plunge of the Wortham structure, facts which were not appreciated until later.

The first two wells which produced Woodbine oil on the Wortham structure were the Boyd Oil Company's Boyd No. 1, completed for 1,000

TABLE VI

PRODUCTION FIGURES FOR THE WORTHAM POOL (IN BARRELS)

Date	Month's Production	Total Production for Year	Total Production for Field to End of Year
December, 1924	867,338	888,856	888,856
December, 1925	419,070	15,946,673	16,835,529
December, 1926	150,362	2,801,123	19,636,652
December, 1927	....	1,134,231	20,770,783

barrels initial yield on November 22, 1924, and the Boyd Oil Company's Simmons No. 1, completed for 8,000 barrels initial yield on November 26, 1924, both wells located by Frank W. DeWolf and the geological staff of the Boyd Oil Company. The sites for these wells were based on a fairly accurate knowledge of the position of the surface fault and on the assumption that this fault had a relatively low dip like that of the faults bounding other pools in the Mexia fault zone.

The completion of the Boyd Company's two wells initiated a remarkably vigorous campaign of drilling, since the field was divided into many leases held by companies and individuals. One week after these two wells were brought in there were already forty or fifty rigs in process of construction or actually drilling. Four months after the discovery of Woodbine oil here the field was more than 95 per cent drilled up.

The peak production was 3,514,194 barrels, in January, 1925, from 158 wells. The production figures are given in Table VI.

Since Woodbine oil was discovered at Wortham, a little oil and gas

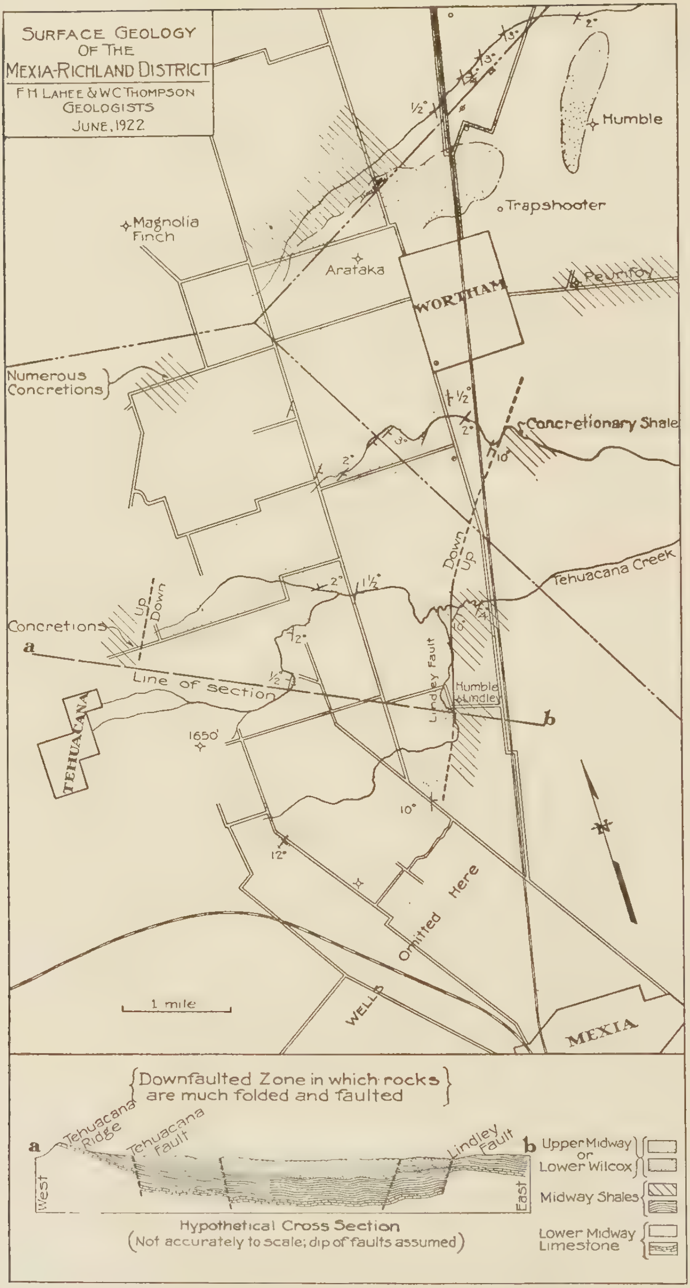


FIG. 10.—Early surface map of the Wortham fault (called the "Lindley fault" on this map).

FIG. 11.—Lease and well map of Wortham field. Depths are marked against wells drilled below the main Woodbine "pay." The discovery and second wells are both shown. The circled gas wells near the eastern edge of the field produced from the 600-foot sand (see text; also see Fig. 27). Scale in feet.

have been found above the Austin chalk. On the eastern side of the field gas was encountered by Carter and Lytle in their Manning No. 2, at a depth of about 600 feet (Fig. 11). This well made about 5,000,000 cubic feet per day, the flow being used for fuel. In January, 1925, the Humble Company completed their Crouch No. 10 A, a 7,000,000-cubic-foot well, at a depth of 628 feet. This gas sand may be the upper part of the Nacatoch (p. 327).

At the southwest end of the field, the Pure Oil Company, in October, 1925, completed their Boyd No. 25 S, which flowed 60 barrels per day for two weeks from a sand at 1,330–1,401 feet. Subsequent drilling failed to develop this sand (probably downthrown Nacatoch) as a commercial "pay," although two or three other wells were finished in it.

At the north end of the field, also, some oil was uncovered at shallow depth, as in Mike Kouri's Munger No. 1, producing from the Nacatoch sand at 1,190 feet, but again the results were disappointing.

Nigger Creek field.—Although it is not the writer's purpose, in this paper, to discuss the structure and general relations of the Nigger Creek field, it is believed that a few words here with reference to its discovery

may be of interest. All the fields previously described are located on a series of faults which together constitute a single fault zone (Fig. 2). The Nigger Creek field was the first field to be discovered producing Woodbine oil from a fault structure parallel with, but not actually within, the true Mexia fault zone. This pool is situated in a zone of faulting, similar to the Mexia zone, but lying $3\frac{1}{2}$–$4\frac{1}{2}$ miles west of the Mexia zone. This may be called the Tehuacana zone of faulting.

The discovery well, the Transcontinental Oil Company's Rosson No. 1, was completed for 2,800 barrels initial yield on July 8, 1926. Credit for the discovery belongs to Leon J. Pepperberg and Heath M. Robinson for mapping the structure and recognizing the possible importance of a "back-fault structure" for production, and to W. E. Wrather for his success in prevailing upon the Transcontinental Oil Company to drill the structure.[1]

The peak of monthly production at Nigger Creek was reached in September, 1926. It was 412,223 barrels. By December, 1926, the production had diminished to 217,786 barrels. The total production of the field was 1,572,899 barrels in 1926, and 972,291 barrels in 1927.

Cedar Creek field.—On August 30, 1927, a second "back-fault" pool (Fig. 2) in the Woodbine sand was opened by the Moutray Oil Company and Reiter and Lewis in their Ward No. 1, which yielded an initial flow of 160 barrels per day from 2,879 feet, later increasing to 550 barrels after being deepened to 2,886 feet. Probably on account of poor sand conditions, this pool has been a disappointment. So far it gives indications of being very small, for the structure is closed in against the fault both northward and southward.

For the week ending November 9, 1927, there was a total daily yield of 625 barrels from 6 wells. This field produced 86,285 barrels in 1927.

Conclusion.—In concluding this review of the history of development in these fields the writer wishes to point out how few of the pools were discovered through a knowledge of the true structural conditions. The Mexia, Groesbeck, Currie, North Currie, and Powell pools were all found by wells located on supposed anticlines. Richland was discovered by a well drilled on the general trend of the fault zone. Only Wortham, Nigger Creek, and Cedar Creek were opened by wells located with reference to the mapped outcrops of the controlling faults. It is interesting, further, to notice that the discovery wells of the Powell, Richland, and Currie pools were drilled, in each case, near one of the extreme ends of the pool. The reason for the indefiniteness of some of the first well locations was

[1] *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), p. 997.

due to the scarcity of outcrops and the generally widespread soil cover.

Up to December 31, 1927, the seven oil pools (Mexia, Currie, North Currie, Powell, Richland, Wortham, and Nigger Creek) had produced a total of 212,544,366 barrels from 7,480 acres, or 28,308 barrels per acre.

STRATIGRAPHY

Formations in the Mexia fault zone.—For the purposes of this paper the writer will describe at some length the strata exposed on the surface or encountered in drilling in that part of the Mexia fault zone which is in Limestone, Freestone, Navarro, Henderson, and Kaufman counties. The youngest formation in this area is the Wilcox,[1] of Eocene age. Below this is the Midway formation, which constitutes the lowermost part of the Eocene. This rests upon the Upper Cretaceous group of formations, which are, from youngest to oldest, the Navarro, the Taylor marl, the Austin chalk, the Eagle Ford shale, and the Woodbine sand. The Lower Cretaceous, or Comanchean, lies below the Woodbine sand.

The Wilcox formation.—The Wilcox formation within the belt of country under discussion is primarily sandy, weathering to a yellowish- or brownish-red sandy soil. It consists, near the base, of alternating thin, rather soft grayish or yellowish sandstones and gray shales, and some thicker beds of massive friable sandstone. Many of the alternations of shaly sand and sandy shale are so thin that the exposures are distinctly laminated. Within this basal part large, irregularly rounded, massive limy concretions may be found. Cross-bedding in the thicker sandstone beds is common. A characteristic feature is the presence of lignite, either in beds or more commonly as thin streaks and isolated pockets, and also as chips scattered through the rock. Even the finer sandy shales may contain microscopic fragments of lignite. This feature of the Wilcox has been used to distinguish it from certain lithologically similar phases of the Midway.

Plant impressions indicate that the Wilcox was of freshwater origin. Animal remains, both megascopic and microscopic, are almost entirely wanting. Near the base, however, or, according to some paleontologists, at the base, is a zone which contains many specimens of *Ostrea tasex* and other fossils, especially gastropods. This horizon has been traced for many miles along the strike. It has been reported in Guadalupe, Caldwell, Bastrop, Milam, Limestone, Freestone, and Navarro counties.

The Midway formation.—Because the Midway is the most widely

[1] The Tertiary Wilcox of Texas and the Gulf Embayment must not be confused with the much older Mississippian "Wilcox" of Oklahoma and Kansas.

outcropping formation where the faults of the Mexia zone come to the surface it has received much intensive study in the effort to discover more faults. It has been subdivided into a lower part, ranging from 75 to 125 feet thick, and an upper part, 500 to 550 feet thick.[1] These two divisions are characterized by distinct faunas.

The upper Midway is composed of clays and soft shales grading upward into sandy shales. Within this subdivision there are several zones which can be distinguished by the concretions which they contain. These concretions proved to be of much assistance in detail surface mapping, since, except for these, the upper Midway weathers down to a gray clayey soil. Some of the major faults were roughly located by mapping these belts of loose concretions.

The lower Midway is much less uniform than the upper in its lithology. Although the upper consists chiefly of marine clay-shales, the lower contains beds deposited nearer the shore. The most conspicuous part of the whole Midway is the whitish-gray or yellowish Tehuacana limestone, or "Midway limestone," which is the uppermost member of the lower Midway.[2] Where this limestone is well exposed it is hard and forms prominent outcrops and escarpments. It is essentially a fragmental rock, composed of broken shell fragments with fish teeth and scales and a quantity of pebbles, sand grains, and glauconite. It is evidently a nearshore deposit, practically a beach deposit, and as such must be situated very near the original inner margin of the Midway sea.[3]

The Tehuacana limestone is not present everywhere throughout the Midway, even in the limited territory here being considered. It is well represented in Limestone County on the Mexia structure and west of this structure; also on the hill on which is situated the town of Tehuacana. It is nearly 200 feet thick in certain wells in southern Limestone County. Yet a few miles northward from Mexia, along the strike, it is absent along the course of Tehuacana Creek (Fig. 10), where its place seems to be taken by a fossiliferous sandstone. In Tehuacana Ridge it is about 60 feet thick. Northward from Tehuacana it forms a prominent escarpment $3\frac{1}{2}$ or 4 miles west of the main Mexia fault zone. East of this ridge it does not crop out in the zone of the producing fields, although it is encountered at shallow depths in many of the wells in the North Currie

[1] Helen J. Plummer, "Foraminifera of the Midway Formation of Texas," *University of Texas Bull. 2644* (1926), p. 13.

[2] W. C. Thompson, "The Midway Limestone of Northeast Texas," *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 6 (1922), pp. 323–32.

[3] W. C. Thompson, *op. cit.*, p. 331.

field (p. 340). Figure 12 illustrates the differences in thickness of the lime as determined by diamond drilling between Richland and Currie. The lime seems to be absent from the vicinity of Angus, in Navarro County, northward to Kaufman County, where it reappears with its characteristic facies, although relatively thin (3–10 feet). The Tehuacana limestone member is thus very irregular in its thickness and in its lithologic character. In some localities it is double, with a sandy phase between the limes.

Below the Tehuacana limestone is the lowermost Midway, which in many places consists of laminated sandy shales and beds of more or less glauconitic sand with fossil fragments. This basal member is also irregular in thickness. At the limestone quarry east of the western main road from Corsicana to Richland, 3 miles northwest of Richland, it is practically missing, the Tehuacana lime there resting almost directly upon the Navarro. On the other hand, on the west side of Tehuacana Ridge 20 or more feet of pack sand rests upon 90 feet of sandy clays and compact clays, all between the Tehuacana limestone and the Navarro formation. These differences are no doubt largely due to the original inequalities in the old Navarro surface on which the Midway sea encroached. Figure 13 shows the local irregularities in the interval between the base of the lime and the top of the Navarro in the North Currie district.

Navarro formation.—The Navarro, uppermost member of the Upper Cretaceous, lies disconformably below the Midway. As previously explained, the basal Midway, where it rests on the Navarro, differs from place to place. There is a variation of more than 100 feet in the stratigraphic position of the contact within the Midway.

For the most part the upper Navarro is a compact to finely laminated gray clay, with a marked conchoidal fracture. It is generally finer and smoother and less sandy than the overlying Midway shales and clays. A few hundred feet below the disconformity (top of the eroded Navarro) is a zone of shaly sands and true sands, more or less glauconitic, forming the Nacatoch sand member of the Navarro. In some localities, notably near Richland, the upper Navarro clays become progressively more marly downward, changing into a thin hard limestone layer which caps the Nacatoch sand zone. This sandy zone ranges from 150 to 250 feet in thickness. It is not the same in all places, but as a rule contains one or more distinct sands, which may carry water or, on favorable structure, oil or gas. This is the pay zone in several of the shallow pools in this territory.

Below the Nacatoch sand is more sandy shale to the base of the for-

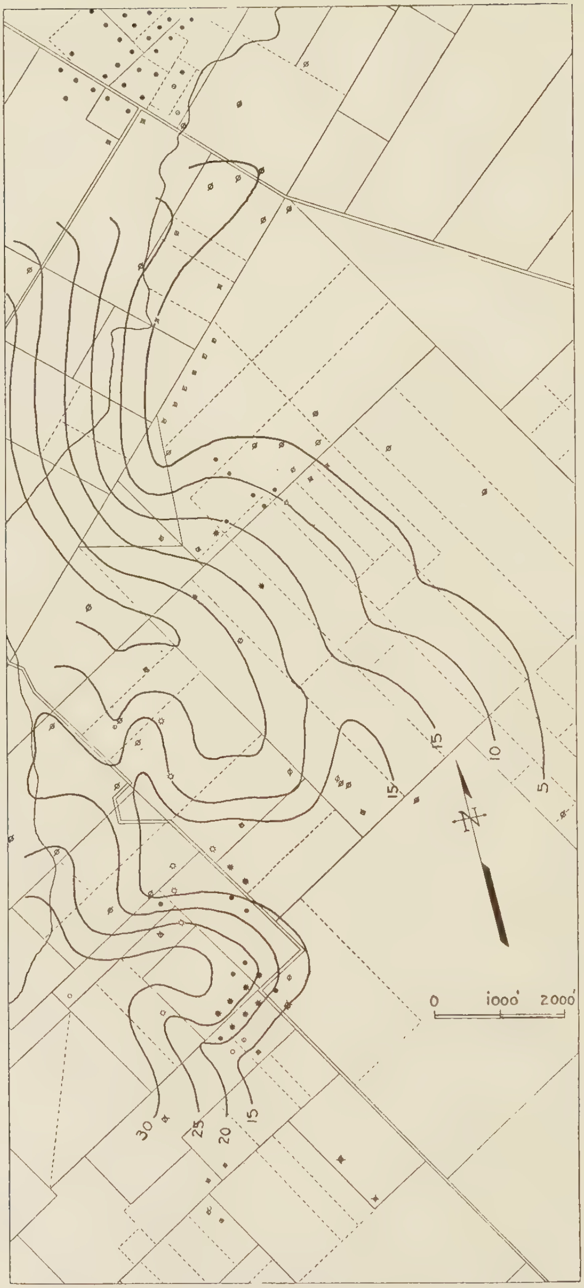


FIG. 12.—Map showing, by lines of equal thickness in feet, the variations in thickness of the Midway lime in the area of North Currie field. Scale in feet.

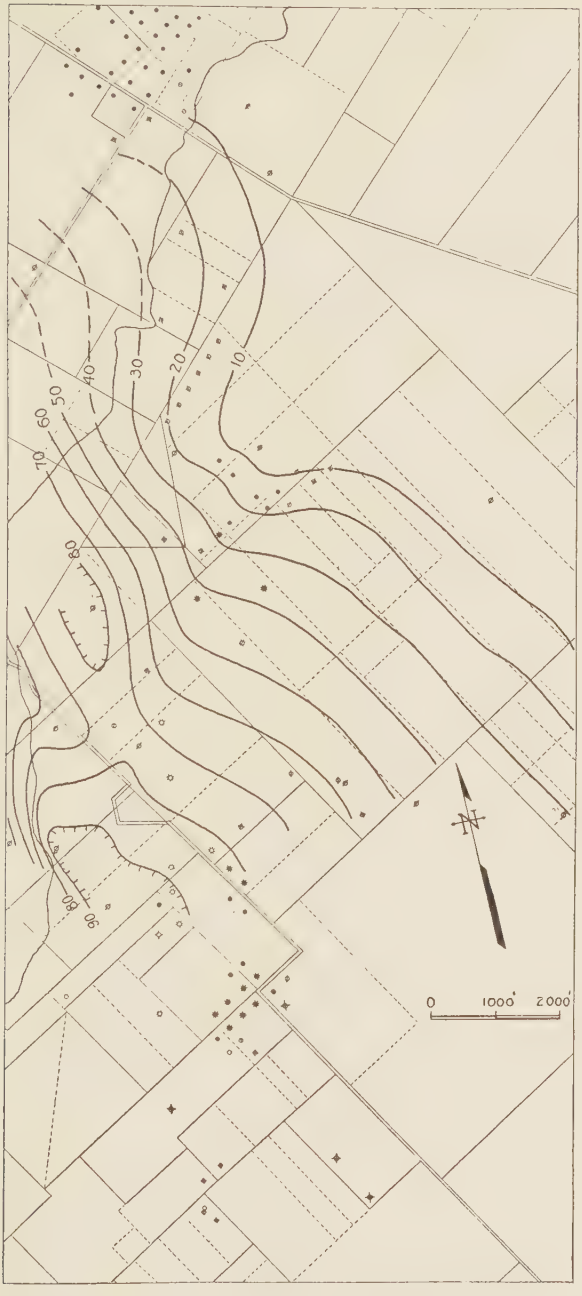


FIG. 13.—Isopach map showing, in feet, variations in the interval between the top of the Midway lime and the top of the Navarro formation, in the area of the North Currie structure. Scale in feet.

mation. Dane and Stephenson put the base of the Navarro at the base of the so-called *Exogyra cancellata* zone,[1] which is 300 feet, more or less, above the Pecan Gap chalk. The Nacatoch sand seems to represent a sandier phase of the Navarro some distance above the base of the *Exogyra cancellata* zone. The Navarro rests disconformably on the uppermost member of the Taylor marl. The total thickness of the Navarro in the Limestone–Navarro County region is between 800 and 1,000 feet.

The Taylor formation.—The uppermost member of the Taylor formation, or "Taylor marl," is a marly shale which is approximately 400 feet thick in Kaufman County, but thins southward to 250 feet in Falls County.[2] Below this is the Pecan Gap chalk, also called the Taylor chalk, to distinguish it from the Austin chalk. The Pecan Gap chalk has not been reported by drillers in most of the wells on the upthrown, or eastern, side of the Mexia zone faults, whereas on the downthrown side it has been described as a definite chalk or even as a limestone in many holes. This may be due partly to the fact that the Pecan Gap may be somewhat harder and more mineralized on the downthrown side, through the agency of more freely circulating waters, and partly to the fact that the driller, usually unaware of the location of this fault, was expecting to find Austin chalk at about the depth where the Pecan Gap was encountered. Actually the Pecan Gap chalk probably underlies all of the area discussed in this paper, although locally it may grade into a marl, as it does southward along its outcrop.

In counties north of this area, a friable sandstone underlying the Pecan Gap chalk is known as the Wolfe City sand.[3] From log correlations it would seem that the sand which produces oil just east of the town of Corsicana, locally designated the Corsicana sand (p. 359), may be equivalent to the Wolfe City member. Showings of oil are widely reported from the zone which includes the Pecan Gap and the Wolfe City sand. The top of the Pecan Gap chalk is approximately 850 feet above the Austin chalk. The top of the Corsicana sand is from 550 to 600 feet above the Austin chalk. The Corsicana sand is really a sandy zone with several sands and intervening sandy shales. It is from 100 to 150 feet in thickness. Below it the Taylor consists of shales and marls. Locally, as

[1] C. H. Dane and L. W. Stephenson, *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 12 (1928), pp. 41–58.

[2] C. H. Dane and L. W. Stephenson, *op. cit.*, pp. 46, 55.

[3] L. W. Stephenson, "Notes on the Stratigraphy of the Upper Cretaceous Formations of Texas and Arkansas," *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 11 (1927), p. 11. Also C. H. Dane and L. W. Stephenson, *op. cit.*

in the Edens pool (Fig. 31), sand which may contain oil or gas is reported about 180 feet above the Corsicana sand.

Stephenson states that the Taylor is unconformable on the Austin chalk from Hill and Comal counties southwestward, but that these formations are apparently conformable from Ellis County northeastward.[1]

The Austin chalk.—The Austin chalk is composed of chalk and chalky limestone which are bluish-gray when freshly exposed, but weather white on the outcrops. It contains some interbedded layers of softer, more shaly material. Its upper contact is difficult to determine accurately, particularly in the logs of wells, since there is a gradational lithologic change from the Taylor into the chalk. As determined from drilling, the average thickness of the Austin chalk increases from 350 feet in the Groesbeck district in southern Limestone County to 440 feet in the Mexia-Richland area, and still more, to as much as 480 feet in the Powell district. The Austin chalk is unconformable on the Eagle Ford shale.[2]

Eagle Ford.—The change from Austin chalk to Eagle Ford shale is more abrupt, and therefore serves as a better key for structural correlations of well logs, than the Taylor-Austin contact. Yet even here mistakes are possible on account of the presence of thin shale beds in the chalk or thin limestone beds in the Eagle Ford near the surface of contact.

The Eagle Ford is a dark, more or less carbonaceous shale. It has a few layers of platy limestone and limy concretions which, in wells, may be reported as "shells." Fish remains, such as scales, bone fragments, and teeth, are common in it. In many localities it is distinctly bituminous, so much so, indeed, that chips of it will ignite if held in a flame. Thin sandy layers in it may carry oil showings.

Northward, in Kaufman County and other northeast Texas counties, a thin sand, referred to as the Blossom, may be present at the top of the Eagle Ford, just below the Austin chalk. In some wells this has been reported to contain a little oil. It does not seem to occur in the Eagle Ford of Limestone County. The formation as a whole becomes somewhat more sandy northeastward.

Near the base of the Eagle Ford, in a zone 50 feet thick, more or less, just above the Woodbine formation, the shale is dark and flecked with little whitish spots. It is called by the drillers the "pepper and salt shale," or the "speckled shale," and is valued as an indication that the Woodbine is not many feet below. This peculiar basal phase of the Eagle Ford is

[1] L. W. Stephenson, *op. cit.*, p. 12.

[2] *Ibid.*, p. 7.

recognized from Henderson and Kaufman counties at least as far south and southwest as Medina County. Its texture ranges from fine shale to sandy shale with sand streaks, but all the shaly layers are characterized by these minute spots. It is thin in Kaufman County and disappears eastward. The "speckled shale" is said to be rich in foraminiferal remains and other organic material. The spots or speckles may possibly be disintegrated remnants of minute shells.

The average thickness of the Eagle Ford is between 340 and 350 feet in Limestone and Navarro counties in the Mexia fault zone.

Woodbine formation.—The Woodbine formation, known ordinarily as the "Woodbine sand," is the lowermost division of the Upper Cretaceous. It contains the most important oil-bearing strata of the Mexia fault fields, and has therefore been studied in detail by means of cores and samples secured in drilling. Descriptions of its lithologic features will be given in discussing the several oil fields. In a broad way it comprises deposits laid down in a transgressing sea, and as such is characterized by considerable differences in lithology. The formation includes not only sandstones, but also shales and thin limestones. Oyster shells and chips and fragments of lignite, both indicative of near-shore deposition, are common in the coarser sandy beds. Throughout the belt of producing fields the shales of the Woodbine are gray, but northward in Kaufman County, and also north of the Powell and Bazette faults in Navarro County, red beds are reported associated with the sands. At the outcrop, west of the Mexia fault zone, the Woodbine rests on the Grayson marl of Lower Cretaceous age. Southward, also along the outcrop from McLennan County to Williamson County, the Woodbine rests on a marl thought to be equivalent to the Del Rio clay. Still farther south the Woodbine formation, which has lost its sandy facies and become a clay shale southward from Hill County, lies on the Buda limestone. There is a marked disconformity between the Upper and Lower Cretaceous at the base of the Woodbine.

From well logs in the Mexia zone, the sandy phase of the Woodbine is known to disappear southward in southern Limestone County. In the Groesbeck district there is very little sandstone in the formation. In the Nigger Creek pool and in the vicinity of Tehuacana the uppermost sand of the Woodbine is missing, its place being taken by shale. In deep wells drilled at Groesbeck, at Mexia, and in the North Currie field the lower Woodbine rests on what is probably the Buda limestone.

Lower Cretaceous (Comanchean) system.—Much less is known of the Lower Cretaceous stratigraphy than of the Upper Cretaceous in the Mexia

fault zone, for relatively few wells have been drilled deep below the main Woodbine pay sand. The principal subdivisions are as follows, the youngest being at the top.[1]

Washita division	Buda limestone	
	Del Rio clay	Upper part equivalent to Grayson marl
	Georgetown	
Fredericksburg division	Edwards	
	Comanche Peak	
	Walnut	
Trinity division	Glen Rose	
	Travis Peak (Basal sand)	

Not all these subdivisions have been surely identified from the deep well cuttings. In the Sun Company's H. A. Swink No. C1 on the North Currie structure (Fig. 7), in the E. L. Smith Company's Steubenrauch No. 1 at Mexia (Fig. 4), and in several wells in south Limestone County, a lime ranging from 60 to 85 feet in thickness is encountered immediately below the Woodbine formation and above recognized Del Rio clay (Fig. 14). In these same wells the Del Rio clay ranges from 85 to 100 feet in thickness. Below it is a thick body of limestones with some shale. The Georgetown-Edwards-Comanche Peak-Walnut group ranges from 500 to 550 feet in thickness in the Swink No. C1 and in the Steubenrauch No. 1. Below this group Glen Rose limes and shales were penetrated all the way to the bottom of the hole in each of these wells. The Swink well was drilled through 1,350 feet of Glen Rose (from 4,050 to 5,412), and the Steubenrauch well passed through 1,700 feet (from 4,050 to 5,700). Real sand was found at the bottom of each of these holes, but it could not be definitely classified. It may have been Travis Peak or it may have still been in the Glen Rose. Since points in these holes, at 5,630 feet in the Steubenrauch well, and at 5,358 feet in the Swink well, respectively, have been correlated as the same horizon, we must conclude that there is a southward thickening of the Glen Rose of at least 270 feet in a distance of 13 miles between these wells, and essentially along the strike. At Ennis, 32 miles from the Swink well, or 14½ miles westward up the dip and 25 miles northward along the strike of the formations, a well drilled for water had 840 feet of Glen Rose which would probably be correlated with the 1,350-foot section in the Swink No. C1 well (Fig. 14).

[1] After R. T. Hill, "Geography and Geology of the Black and Grand Prairies, Texas," *U. S. Geol. Survey Ann. Rept. 21* (1900), Vol. 7. See also W. S. Adkins, "Geology and Mineral Resources of McLennan County," *University of Texas Bull. 2340* (1923).

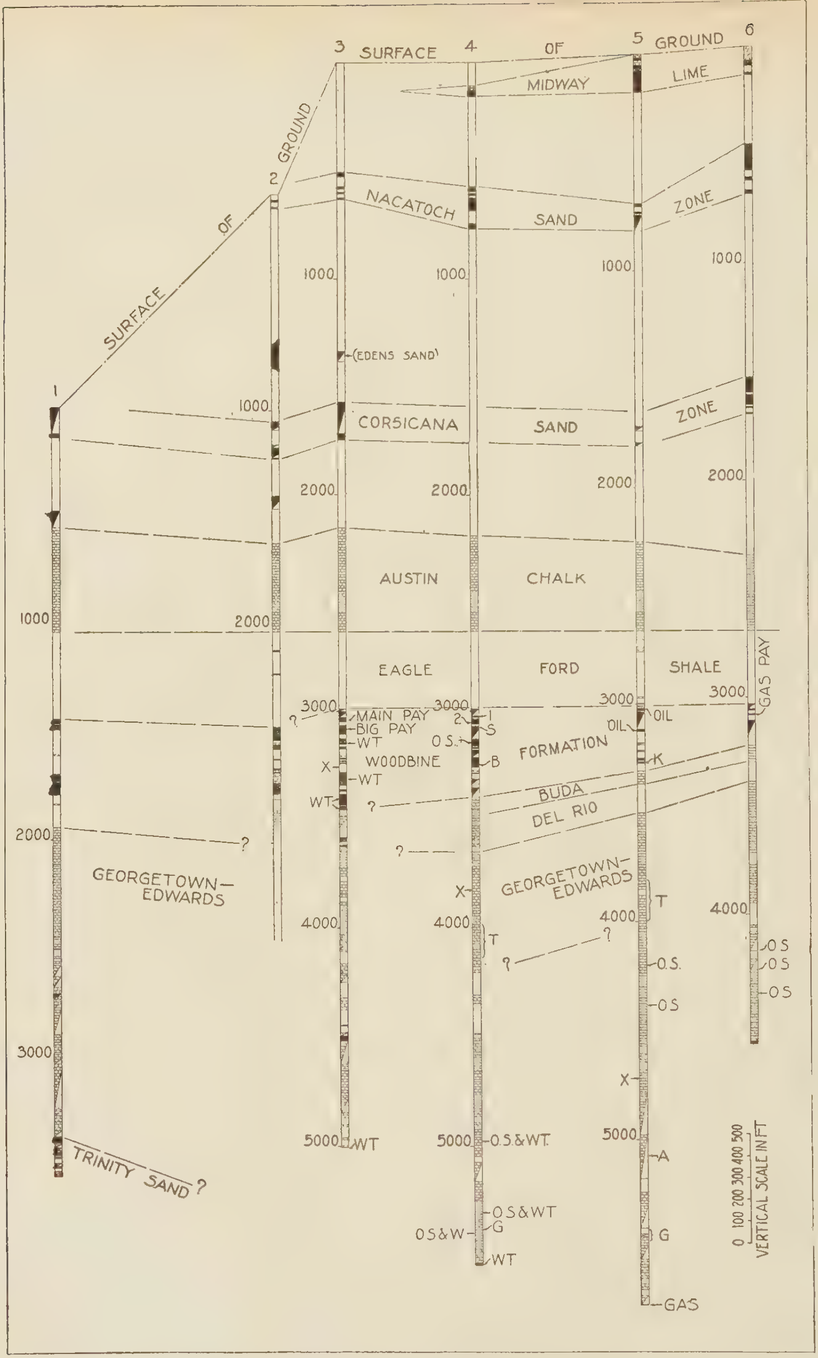


FIG. 14.—Correlation chart of logs in Navarro and Limestone counties. The logs are plotted with reference to the base of the Austin chalk, taken as a horizontal line. The logs are as follows: (1) city of Ennis water well; (2) Cortex Oil Company's Brown well one mile south of Corsicana; (3) type or composite log for the wells in the Powell field, the lower part of the record being from the McMan Oil Company's Chapman No. 8; (4) composite log for the North Currie field, the deeper formations being taken from the Sun Oil Company's H. A. Swink No. C1; (5) composite log for Mexia field, the lower record being taken from E. L. Smith's Steubenrauch well; (6) composite log for the Groesbeck district—*A*, anhydrite found in cuttings; *B*, Barclay & Meadows deep sand; *G*, gypsum cuttings; *K*, Kollman "pay"; *O.S.*, oil show; *S*. Swink "pay"; *T*, *Tritaxia* zone, just above top of Glen Rose; *WT*, salt water; *X*, relative position of bottom of second deepest well in Powell field (No. 3), in North Currie field (No. 4), and in Mexia field (No. 5). In the North Currie field the second deepest well was the Sun Oil Company's H. A. Swink No. 2A; and in the Mexia field, the Humphreys-Mexia Company's Berthelson No. 36. In log No. 4, 1 and 2 are the first and second "pays." Black, sand; brick pattern, lime or chalk; blank, shale.

No wells in the district under discussion have yet definitely entered the Travis Peak formation.

STRUCTURE

General characteristics of the fields.—In the Mexia fault zone, from Limestone County to Navarro County, inclusive,[1] there are now (January, 1928) ten producing structures. Eight of these are in the Mexia fault zone proper. They are, from south to north (Fig. 2), South Groesbeck, North Groesbeck, Mexia, Wortham, Currie, North Currie, Richland, and Powell. The other two, Nigger Creek and Cedar Creek, are situated in a parallel fault zone, $3\frac{1}{2}$–$4\frac{1}{2}$ miles west of the Mexia zone. All these ten pools are located on structures which are similar in that they are folds flanking major faults which have a downthrow on the west. In all cases the displacement is large—several hundred feet—the fault is a strike fault, and its dip is relatively low toward the west.

The average regional dip of the Austin chalk in this part of Texas, in sections carried across the faulted area without regard to westward or eastward downthrow, is 79 feet per mile from south Ellis County to northwestern Anderson County; 81 feet per mile from eastern Hill County to west-central Freestone County; and 88 feet per mile from north McLellan County to southern Freestone County. To a certain extent local drag into the faults of the Mexia zone serves to accentuate anticlinal folding in the upthrown beds, some of the sandy members of which have functioned as reservoirs for oil or gas.

We shall first discuss the features of the individual pools, after which we shall consider some of their mutual similarities and differences and their structural relations.

Mexia.—The Mexia anticline is one of the two longest, and is the widest, of the producing structures in the Mexia fault zone. The oil-bearing part of this anticline is 36,000 feet long, and has a maximum width of 7,000 feet. The crest is in the Humphreys-Mexia's (now the Pure Oil Company's) J. and J. Nussbaum tract (Fig. 4). The pool has its west edge in the Woodbine sand, where this sand is cut by the major fault.

The outcrop of the main fault is approximately along line *EF* (Fig. 15). East of this line the Midway lime is at or near the surface. West of this line the top of the Midway lime is from 150 to 175 feet below the surface (Fig. 16). Line *CD′D* marks the position of the fault where it cuts the top of the Austin chalk, and line *AB* is the trace of this same fault in the Woodbine pay sand. As seen in Figure 16, the angle of dip

[1] The writer does not consider in this article any of the non-producing faults in these counties, or the fault structures, in the same belt, which yield oil south of Limestone County.

FIG. 15.—Subsurface structure map of the top of the Woodbine main pay zone in the Mexia field, based on an old map of the Humble Oil Company, but with modifications. Used with the kind permission of Wallace E. Pratt. *AB* is the fault in the top of the Woodbine "pay"; *CD*, with a branch, *C′D′*, is the same fault in the top of the Austin chalk; *EF* is the same fault in the Midway lime; *GH* is another fault in the Woodbine; *IJ* is the position of the axis of Clapp's structure (see Fig. 3). The approximate position of the east edge water is shown by a dotted line. *XY* is the line of section of Figure 16. Contours represent depths below sea-level on top of the Woodbine "pay" (see Fig. 4). Scale in feet.

of the fault along the line of the cross section (*XY*, Fig. 15) is about 37.5° west down to the top of the chalk, at which point it steepens very markedly. The total displacement is 550 feet in the chalk. In the Midway lime, at the highest part of the structure, it is between 260 and 300 feet. This means that faulting which produced a throw ranging from 250 to 300 feet in pre-Midway post-Navarro time must have been renewed with further vertical movement of from 260 to 300 feet after Midway time.

The conditions of the faulting at the south end of the structure are complex. The surface fault trace (*EF*) crosses the chalk fault (*CD′*) and the Woodbine fault, suggesting that the fault, normal to the point of crossing, becomes reverse southward beyond this point. The chalk fault (*D′D*) splits into two branches (*C′D′* and *CD′*). Another fault appears (*GH*). There are other surface faults present, roughly parallel with and east of the main surface fault (*EF*), but these are not shown in the figure. North of *D′* the inclination of the fault from the chalk top to the Woodbine top is not as steep as it is south of *D′*. To unravel these complications of structure from the well logs is difficult and their interpretation is open to some difference of opinion. The object here is merely to emphasize the fact that there are complications, which are especially developed at the south end of the Mexia structure.

A glance at Figure 15 will show two important features. (1) Throughout nearly the whole length of the field, the crestline of the anticline in the Woodbine sand is from 500 to 2,000 feet east of the fault trace in this horizon. (2) The fold is distinctly asymmetrical, the dip on the west side of the axis being at least twice as steep as that on the east flank. In Figure 3 the axis of the Mexia structure in the "gas sand," or Nacatoch sand, is shown as a dashed line. This line is represented by *IJ* in Figure 15. The reader will therefore notice that the axis of the fold in the Nacatoch sand, which is from 2,200 to 2,300 feet stratigraphically above the Woodbine pay sand, ranges from 1,000 to 2,500 feet east of the axis of the same fold in the Woodbine sand. It approaches nearest where the fold is highest.

These facts—the asymmetry of the fold and the progressive westward shift of the axis, roughly parallel with the fault, as one goes deeper in the formations—point very strongly to the inference that the fold as a whole had its origin intimately related to the origin of the faulting. If the fault were a subsequent and incidental result of the folding, we should have to assume an overthrust force from the east or an underthrust force from the west to account for the type of asymmetry exhibited by the fold. Since the tendency in this part of Texas is toward settling into the East Texas basin, the first hypothesis of an overthrust from the

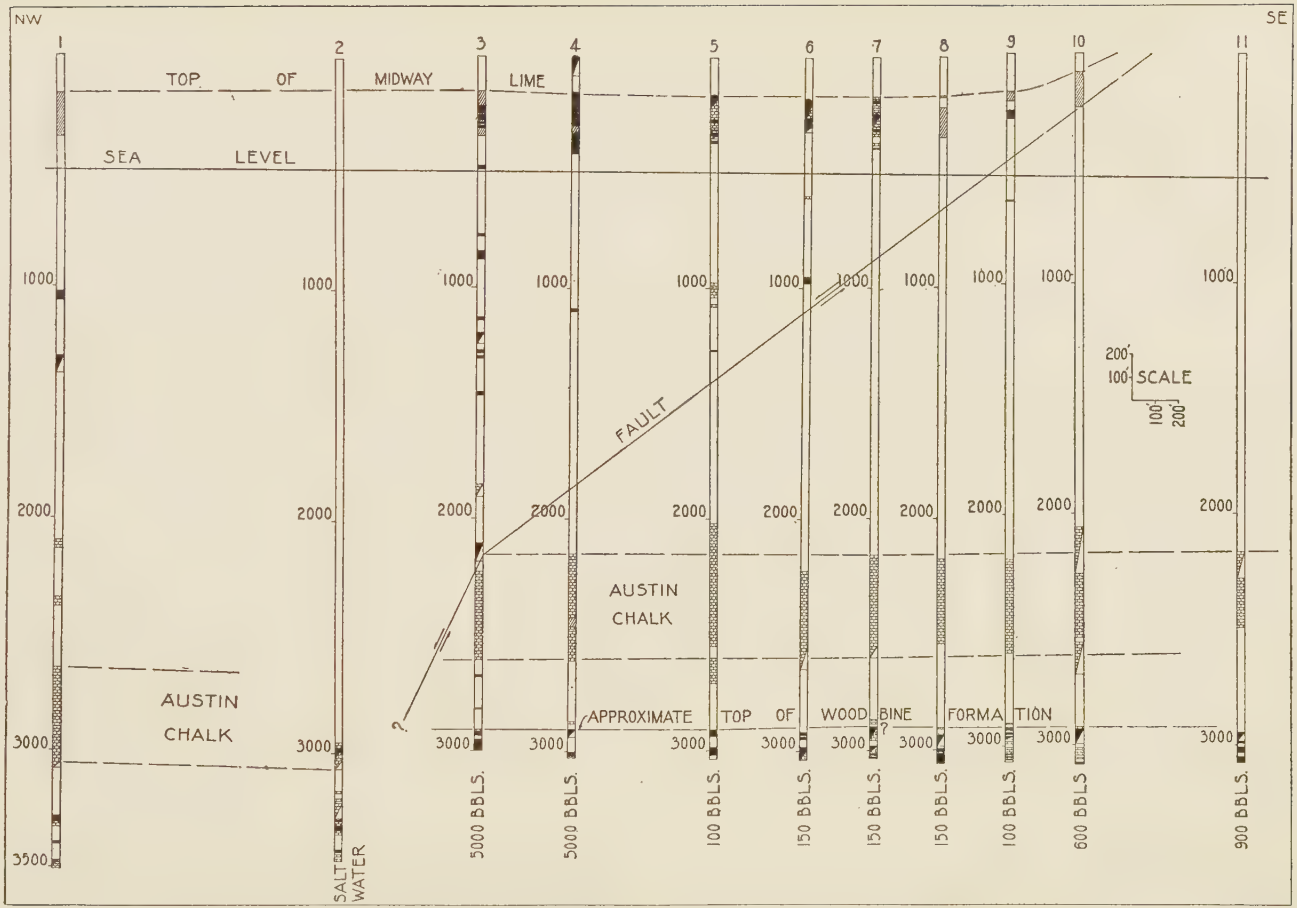
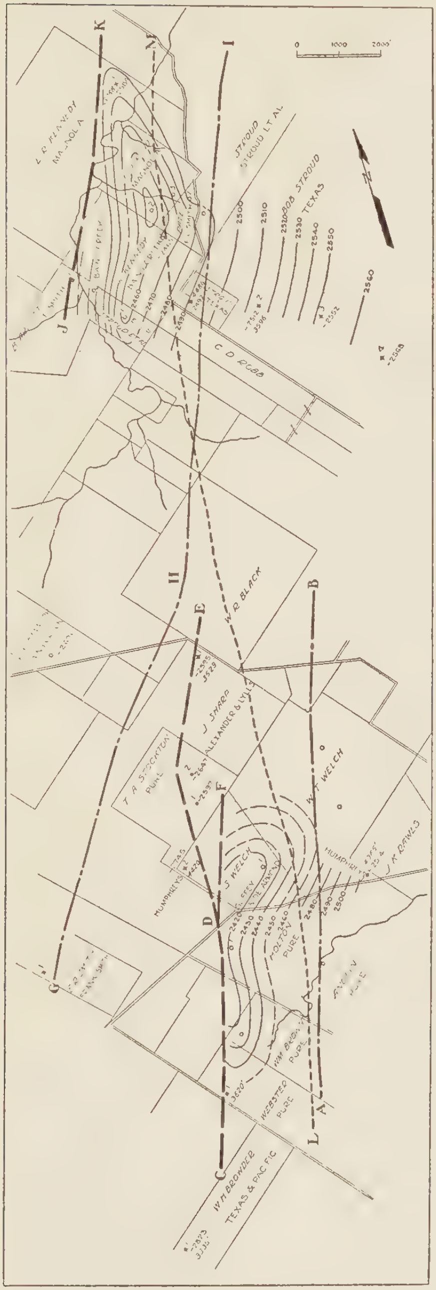


FIG. 16.—Log section of the Mexia structure (see XY, Fig. 15). Logs are plotted to sea-level. Initial productions shown at bottom of each record: (1) Kirby Petroleum Company's Nussbaum No. 4, (2) same company's Nussbaum No. 5, (3) same company's Nussbaum No. 2, (4) Humphreys' Kendrick No. 1, (5–10) Humphreys' Kendrick No. 6 to No. 11, respectively, (11) Humphreys' Berthelson No. 27. Black, [illegible] blank, shale. Scale in feet.



east would be untenable. On the other hand, an underthrust from the west would not be likely to produce major faulting with low *west* dip in the *same stratigraphic prism* within which the fold had its steepest flank on the *west* side of the axis. We conclude, then, that the Mexia fold is a feature developed as a consequence of, and in connection with, the associated major fault.

Groesbeck.—On his subsurface map of the structure in the Nacatoch gas sand (Fig. 3) Clapp showed three major closures on the main anticline. The northernmost of these three is the Mexia structure. The middle closure, just south of Navasota River, is the North Groesbeck structure, and the southern of the three is the South Groesbeck structure. The writer has indicated the position of Clapp's axis on the map of the Woodbine structures in these Groesbeck pools (Fig. 17). As in the

FIG. 17.—Lease and subsurface structure map of the Woodbine pay sand in the North and South Groesbeck fields. *AB*, surface fault; *CDF*, same fault in the Woodbine pay sand, with a branch, *DE*. *GHI*, surface fault of the North Groesbeck structure, and *JK*, its intersection with the top of the Woodbine "pay." Depths of wells drilled below the main "pay" are indicated. The dashed line (*LM*) shows the position of the axis of Clapp's structure in the "gas rock" (see Fig. 3). Contours show depths of main Woodbine "pay" below sea-level. Scale in feet.

Mexia fold, here also the axis of the fold in the Nacatoch lies east of the axis of the same fold in the Woodbine, but more so on the south structure than on the north structure. Very likely the crest of the North Groesbeck anticline would be found to lie farther west if more drilling were done west of the Magnolia's Stroud No. 2.

The Groesbeck pools are small, and, except for the Pure Oil Company's Stockton oil wells No. 1 and No. 2, they produce gas from the Woodbine sand. These oil wells lie between two branches (*DE* and *DF*, Fig. 17) of the main fault.

This map emphasizes the fact that these two pools are on closures associated with faults which are situated *en échelon* with respect to one another. They are not on a single structure, as suggested by Figure 3. *GHI* is the surface outcrop of fault *JK* and *AB* is the outcrop of *CDF*. The approximate displacement of each of these faults is 400 feet, with downthrow on the west.

Currie.—The Currie pool is 11,000 feet long and 3,000 feet wide at its widest part (Figs. 5 and 18). The fold is irregular as compared with Mexia and Wortham. Its highest points are just above 2,500 feet below sea-level.

The fault associated with this field has a very obscure outcrop. It cuts the chalk in line *CD* and the main Woodbine "pay" in line *AB* (Fig. 18). About 250 feet below the Woodbine "pay" is the deeper Woodbine pay sand, locally called the Morrow "pay." This sand is cut by the fault in line *MN* (Fig. 18). Only a few wells, situated close to the fault, have yielded oil from this "pay." They are underscored in Figure 5.

The general structural relations are shown in Figure 19. The logs are so poor in this field that it was found impossible to determine the true nature of the faulting. This subject has been presented by the writer in earlier papers.[1] Flattening of the fault dip in the Eagle Ford is observed in several sections, but the breadth of the fault zone in the chalk suggests more than one break here. The total displacement is between 450 and 500 feet.

North Currie.—The North Currie structure was primarily a gas structure, although it yielded some oil from the main pay near the ends of the pool. It has produced some oil from the "Swink pay," which is below the main "pay" of the Woodbine. The entire structure has not been

[1] F. H. Lahee, "The Currie Field, Navarro County, Texas," *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 7 (1923), pp. 25–36; and "Further Notes on the Origin and Nature of the Currie Structure, Navarro County, Texas," *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), pp. 61–71.

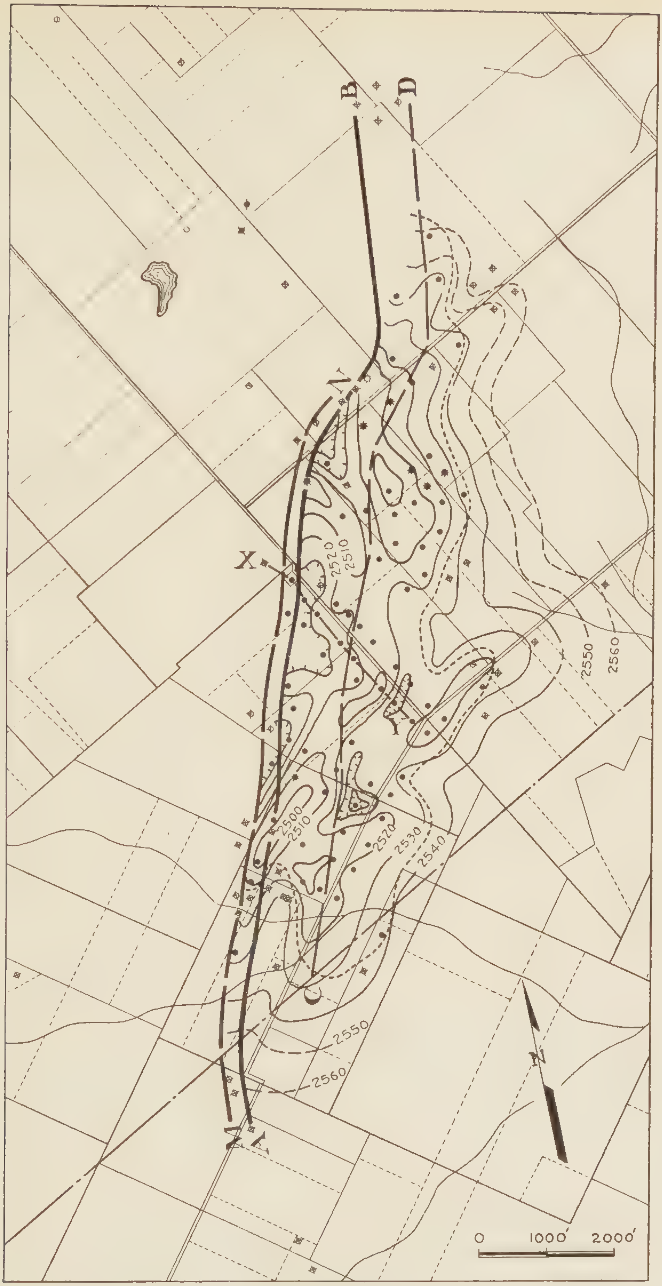


FIG. 18.—Structure map of the Woodbine "pay" in the Currie field (modified from Fig. 2 on p. 63 of *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 10, 1926). The dotted line shows the approximate original edge water contact. *AB*, fault trace in Woodbine; *CD*, trace of same fault in top of Austin chalk; *MN*, trace of same fault in top of Morrow "pay"; *XY*, line of section of Figure 19. Contours show depths of main "pay" below sea-level (see Fig. 5). Scale in feet.

completely drilled to the edge of production, but in general we may say that the pool is about 9,000 feet long, 2,000 feet wide, and has a structural relief of 40 or 45 feet (Fig. 20). The top of the fold is 2,535 feet below sea-level in the Woodbine main pay sand.

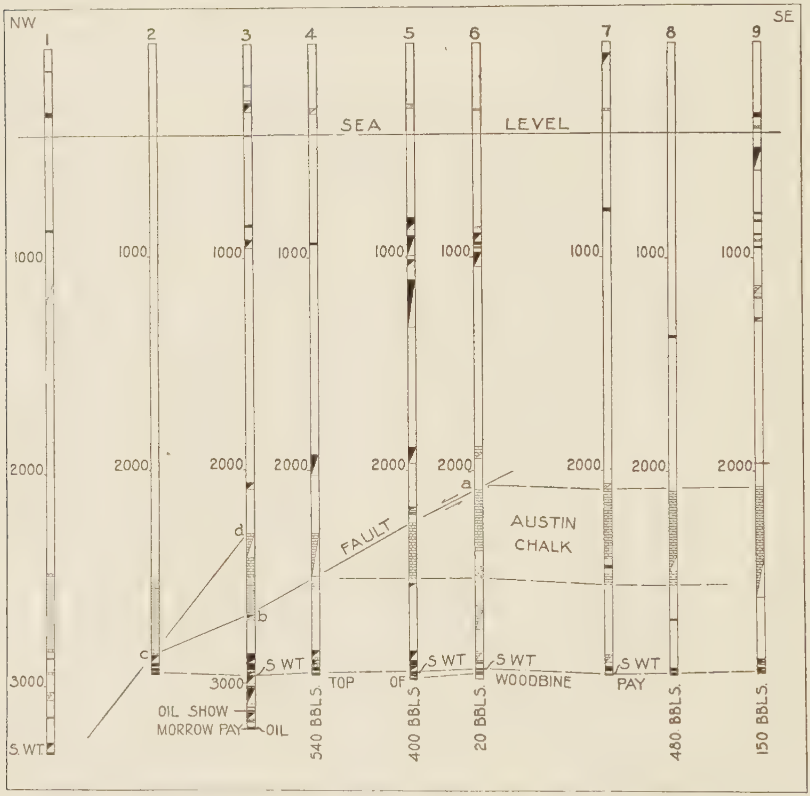


FIG. 19.—Log section of the Currie field (see *XY*, Fig. 18). *S.Wt.*=salt water. Logs are (1) Humphreys' Gamewell No. 1, (2) Atlantic Oil Company's Church Lot No. 1, (3) Atlantic Oil Company's R. V. Bounds No. 3, (4) Gulf Company's R. V. Bounds No. 3, (5) ditto, R. V. Bounds No. 1, (6) Brothers Oil Company's R. V. Bounds No. 5, (7) ditto, R. V. Bounds No. 4, (8) Trapshooter Reilly's R. V. Bounds No. 1, (9) ditto, R. V. Bounds No. 2. Black, sand; brick pattern, lime or chalk; blank, shale. Depths in feet.

The associated fault has its surface outcrop between 2,000 and 3,000 feet east of its intersection with the Woodbine "pay." The distance is greatest near the middle of the length of the structure. Thus, as in the Wortham structure, the fault steepens toward the ends of the fold. Its

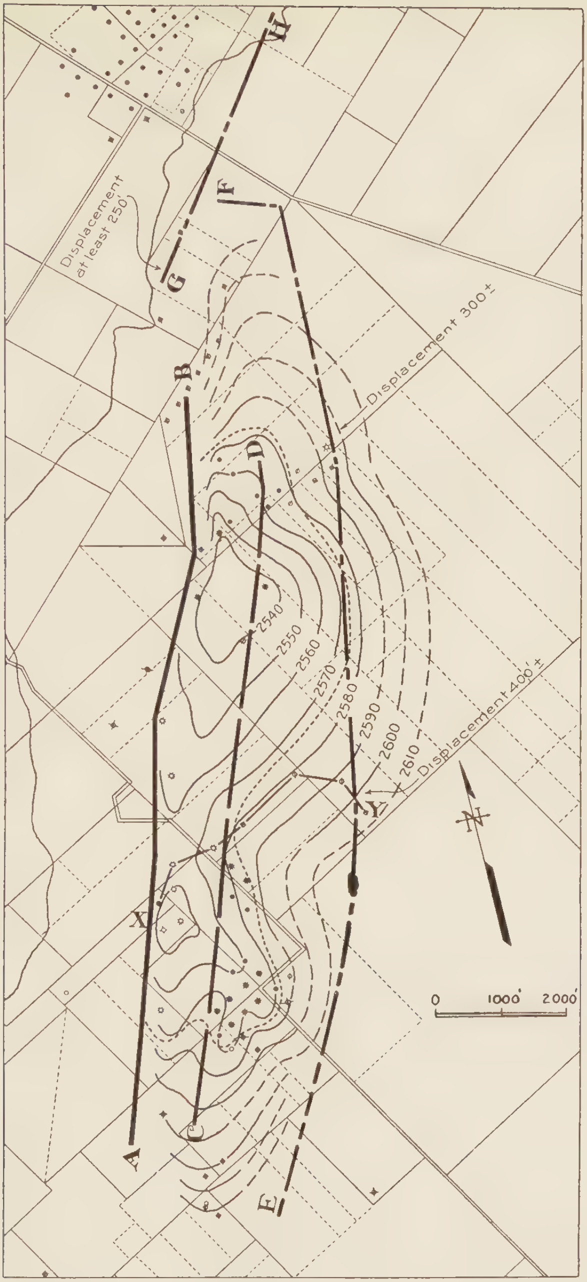


FIG. 20.—Structure of the Woodbine "pay" in the North Currie field. *EF*, fault in Midway lime, not far below the surface (see Fig. 21). *CD*, trace of same fault in top of Austin chalk; *AB*, trace of same fault in Woodbine "pay"; *GH*, southward extension of Midway fault of Richland field; *XY*, line of section of Figure 21. Eastern edge-water contact approximated by dotted line. Contours show depth of Woodbine "pay" below sea-level, in feet (see Fig. 7). Scale in feet.

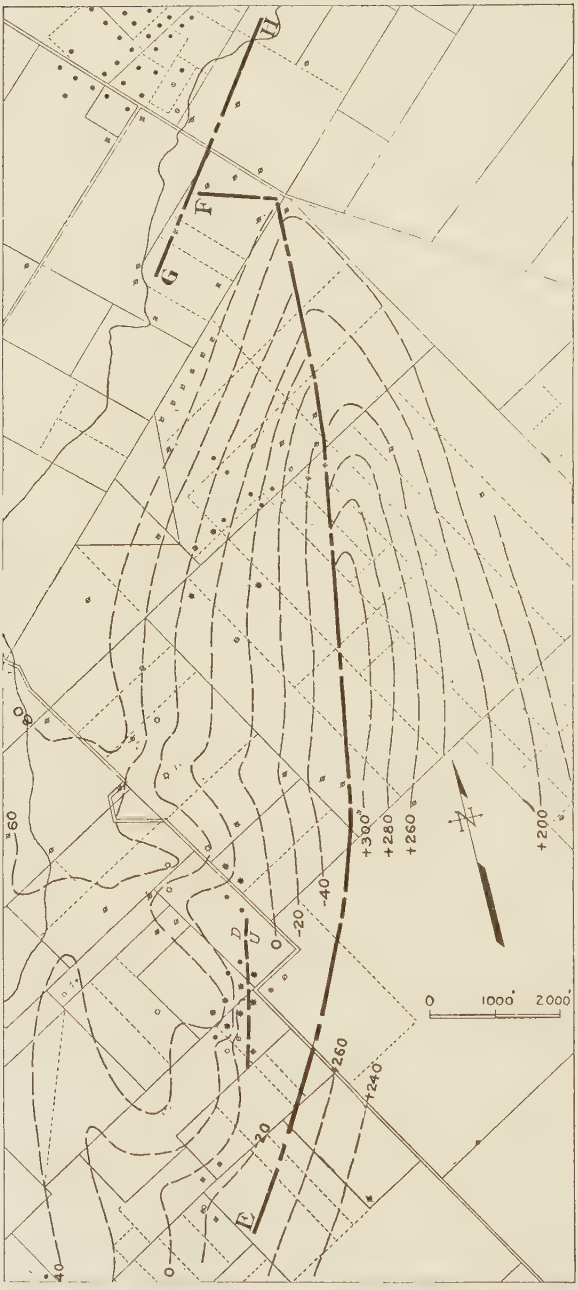


FIG. 21.—Structure of the Midway lime in the North Currie field. Contours show depths above (+) or below (−) sea-level. All faults in Midway lime (see Fig. 20). Scale in feet.

dip is approximately 41° (Fig. 30). The axis of the anticline in the Woodbine is from 300 to 1,000 feet east of the fault in the Woodbine.

Probably none of the producing structures in the Mexia zone has been so thoroughly studied as has this North Currie fold with its associated

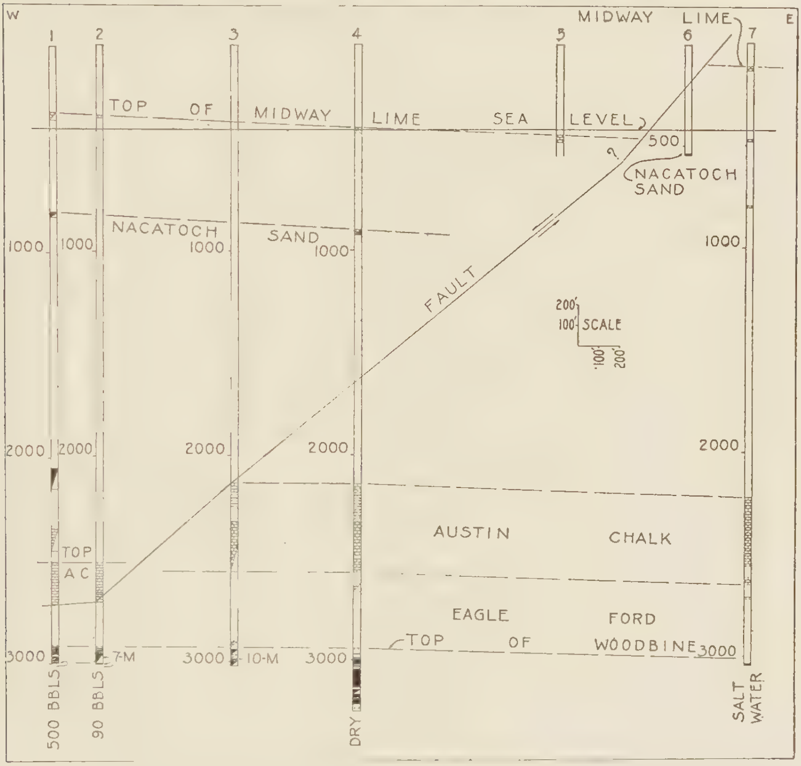
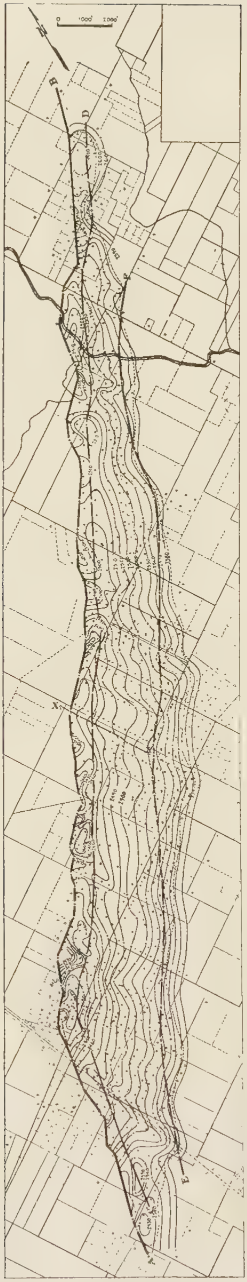


FIG. 22.—Log section of the North Currie field (see *XY*, Fig. 20). *M*, million cubic feet of gas per day. Logs are: (1) Sun Oil Company's E. L. Swink No. 2A, (2) ditto, E. L. Swink No. 1A, (3) ditto, H. A. Swink No. 1B, (4) ditto, H. A. Swink No. 2B, (5) Sun Oil Company's diamond drill hole, H. A. Swink No. BD1, (6) ditto, West No. D8, (7) Panhandle Oil Company's West No. 1. Black, sand; brick pattern, lime or chalk; blank shale.

fault. More than 20 diamond-core holes were drilled here by the Sun Oil Company. All of these holes were carried into the Navarro formation. In addition to this shallow subsurface work, great care was taken in studying the deeper formations. Figures 12 and 13 have already been mentioned (p. 327). In Figure 21 is a contour map of the Midway lime. Part of the information came from core holes and part from the wells



drilled for oil or gas. The fault was closely located from the south end of the Sun Company's C. S. West Estate lease (Fig. 7) to its north end at *F* (Fig. 20). It is not so definitely located along its south extension. The displacement in the Midway is 400 feet (Figs. 20 and 22), which is the same as that in the Austin chalk and the Woodbine. This is interesting in view of the general notion that these Mexia zone faults as a rule have considerably less displacement in the Midway than in the Cretaceous.

Another most interesting result of this core drilling was the discovery of the manner of termination of the fault. The displacement, which was 400 feet near the middle of the length of the break, decreased to 300 feet a mile farther north (Fig. 20). It continued to decrease northward to a point where it abruptly turned west and abutted against the southwestward extension of the Richland major fault (*GH*, Fig. 20). These two faults are thus proved to be distinct and separate breaks. In no other place in the Mexia zone, as far as the writer knows, have the relations of the faults of adjoining fields been so definitely established. Very likely this condition at North Currie and Richland is more or less characteristic of other overlapping faults in the zone.

Referring again to Figure 30, the angle of dip of the North Currie fault averages 41° from the surface of the ground to the top of the chalk.[1] It steepens here, probably more than is shown. It certainly flattens very pronouncedly in the Eagle Ford.

[1] At right angles to strike.

FIG. 23.—Structure of the Woodbine "pay" in the Powell field. After H. B. Hill and C. E. Sutton, with some modifications. The contours show depths of the Woodbine "pay" below sea-level. *EF*, surface fault; *CD*, same fault at top of Woodbine "pay." The dotted line marks the approximate original position of the east edge water. *XY*, line of section shown in Figure 24 (see Fig. 8 for leases and well numbers). Scale in feet.

Powell.—The oil-producing part of the Powell structure is 40,000 feet long and 4,000 feet wide at its widest part (Figs. 8 and 23). The crest of the fold in the Woodbine "pay," located where the fault turns from a southwesterly to a nearly southerly direction, is 2,420 feet below

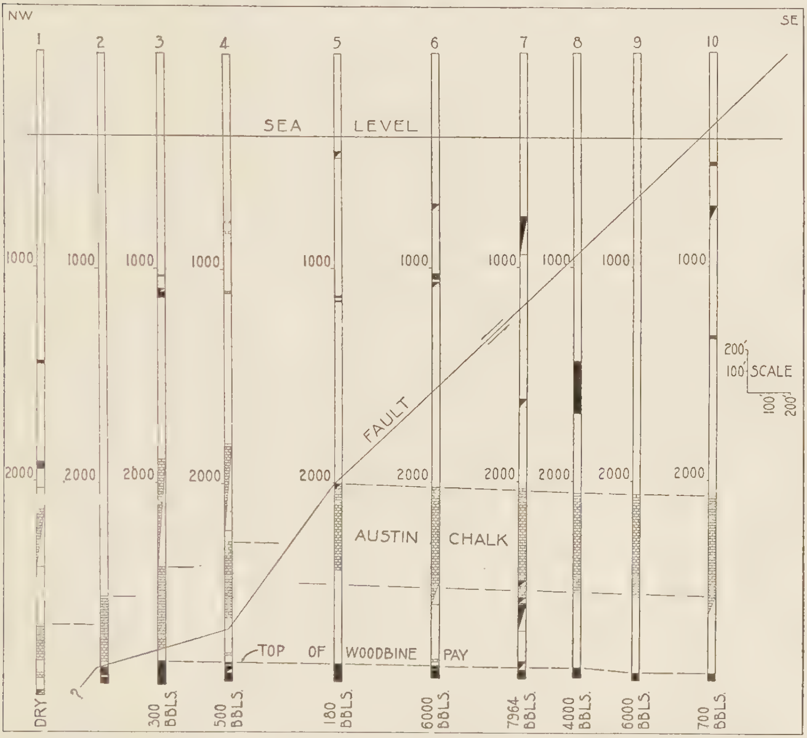


FIG. 24.—Log section of the Powell field (see *XY*, Fig. 23). Logs are: (1) J. K. Hughes' Ramsay No. 1, (2) Humble Ramsay No. 15B, (3) ditto, Ramsay No. 14B, (4) ditto, Ramsay No. 11B, (5) ditto, Ramsay No. 7B, (6) ditto, Ramsay No. 5B, (7) ditto, Ramsay No. 1B, (8) E. L. Smith's Ramsay No. 4, (9) ditto, Ramsay No. 3, (10) ditto, Ramsay No. 2. Black, sand; brick patterns, lime or chalk; blank, shale. Scale in feet.

sea-level. A line connecting the chain of small closures in the Woodbine sand near the western side of the fold (Fig. 23) would lie from 500 to 1,000 feet east of the fault in the Woodbine. Such a line may be referred to as the axis.

The fault is exposed (*EF*, Fig. 23) west of the east edge of production throughout most of the length of the pool. It lies from 1,600 to 3,700 feet east of its intersection (*AB*, Fig. 23) with the Woodbine "pay."

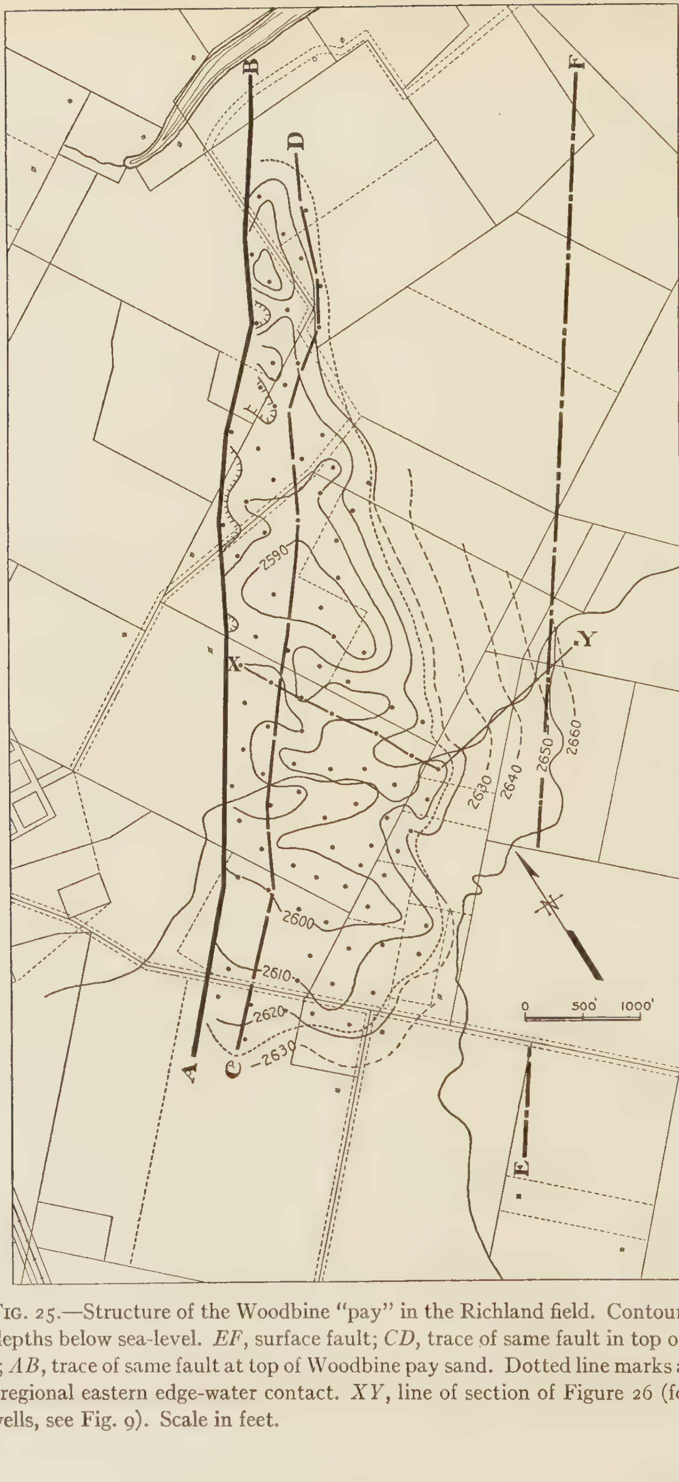


FIG. 25.—Structure of the Woodbine "pay" in the Richland field. Contours represent depths below sea-level. *EF*, surface fault; *CD*, trace of same fault in top of Austin chalk; *AB*, trace of same fault at top of Woodbine pay sand. Dotted line marks approximate regional eastern edge-water contact. *XY*, line of section of Figure 26 (for leases and wells, see Fig. 9). Scale in feet.

These lines (*AB* and *EF*) are most widely separated where the fold is most strongly developed. Toward the north and south extremities they approach. This, then, is another example of the steepening of the fault dip toward the ends of the structure (compare with Wortham and North Currie).

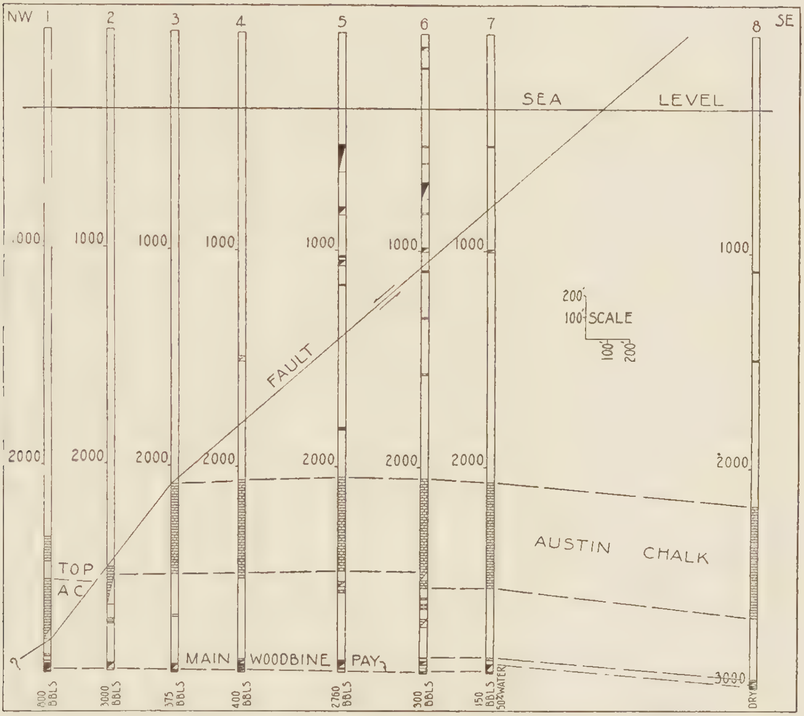
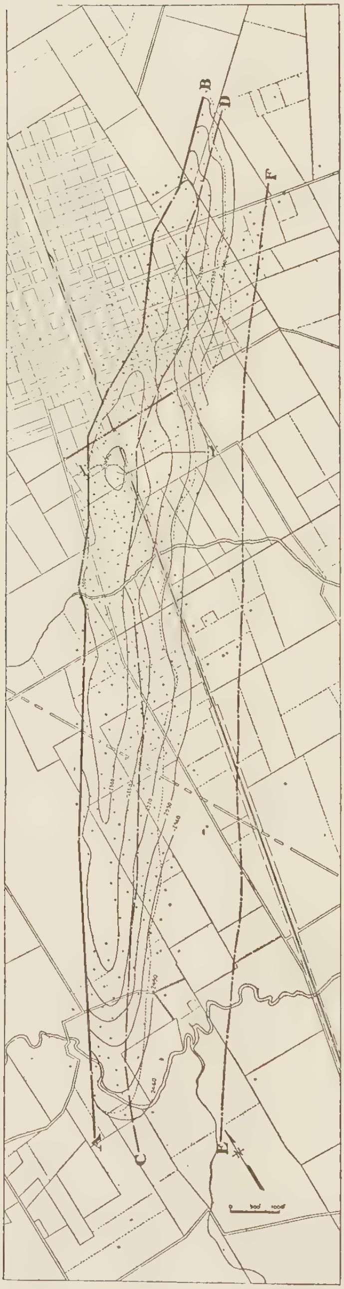


FIG. 26.—Log section of the Richland field (see *XY*, Fig. 25). Logs are: (1) Sun Oil Company's Brown No. 8, (2) ditto, Brown No. 7, (3–6) Sun Oil Company's Brown No. 4 to No. 1, respectively, (7) Wallace Drilling Company's R. R. Davis No. 1, (8) Max Guitman's Swink No. 1. Black, sand; brick pattern, lime or chalk; blank shale. Scale in feet.

The total displacement of the fault is about 650 feet (Fig. 24). The fault surface has an average dip of 50° from the surface to the top of the Austin chalk (Fig. 30). It there steepens to 56°. In the Eagle Ford shale it becomes lower.

Richland.—The Richland pool is 7,500 feet long and has a maximum width of 1,800 feet. The top of the fold in the Woodbine "pay" is about 2,585 feet below sea-level. Like the Currie structure, the Richland anti-



cline is flat and irregular, without a very definite axis, yet there is plenty of evidence of drag into the fault (Figs. 9, 25, and 26).

The fault is exposed about 2,700 feet east of its intersection with the Woodbine "pay." Its dip is about 44° from the surface to the top of the chalk, and 53° from the top to the bottom of the chalk. It probably flattens in the Eagle Ford. Its displacement is about 450 feet.

Wortham.—The productive area of the Wortham pool is 20,000 feet long and 2,000 feet wide at its widest part. The crest-line of the anticline in the Woodbine "pay" lies about 500 feet east of the line where the fault (*AB*, Fig. 27) cuts this horizon. The western edge of production, against the fault, lies 20 feet, more or less, higher than the eastern edge.

The exposure of the fault, *EF*, is from 500 to 1,800 feet east of the east edge of production. The line *CD* where the fault cuts the top of the Austin chalk is not far west of the east edge of production. The surface fault is from 1,800 to 3,200 feet east of its intersection with the Woodbine "pay," the distance being greater near the higher central part of the fold. In other words, the fault dip steepens toward the two ends of the structure. The displacement ranges from 600 to 650 feet

FIG. 27.—Structure map of the Woodbine "pay" in the Wortham field. *AB*, *CD*, *EF*, and dotted line same as in Figure 25. *XY*, line of section of Figure 28. Scale in feet.

(Fig. 28), enough to bring the Wilcox on the downthrown side against the Midway in the upthrown block (Fig. 10). Between the surface and the top of the Austin chalk the fault dips at an angle of 45°. It steepens in cutting the chalk, and then evidently flattens again in the Eagle Ford

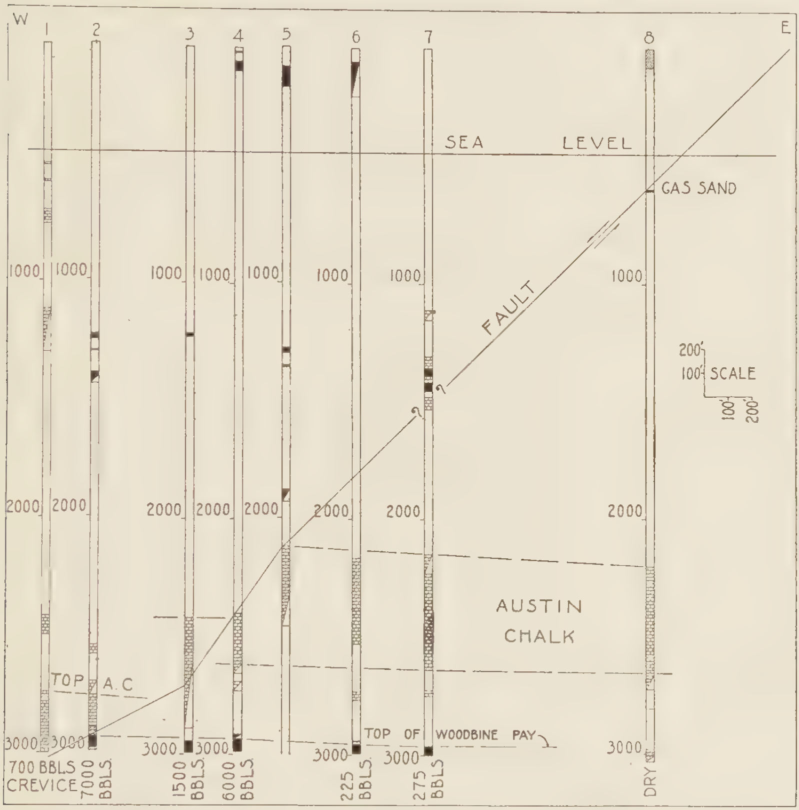


FIG. 28.—Log section of the Wortham field (see *XY*, Fig. 27). Logs are: (1) E. L. Smith's Beal No. 3, (2) ditto, Beal No. 1, (3) Texas Company's Watson No. 1, (4) Rio Bravo Oil Company's H. & T. C. Right of Way No. 4, (5) Humble Oil Company's Crouch No. 1A, (6) ditto, Crouch No. 8A, (7) ditto, Crouch No. 6A, (8) ditto, Crouch No. 2A. Black, sand; brick pattern, lime or chalk; blank, shale. Scale in feet.

shale, so that the average dip, from the surface to the Woodbine pay sand, remains about 45°.

Nigger Creek.—The Nigger Creek field is described by Leon J. Pepperberg.[1] Consequently the writer will not discuss it here further than to

[1] Pp. 409–420.

say that the controlling fault has a throw of 200 feet in the Midway lime, at the high part of the structure, and a throw of 500 feet in the Austin chalk. This is similar to the Mexia structure, where a fault, already in existence before the Midway was deposited, seems to have had its throw increased by more slipping after Midway time.

Summary and general considerations.—Some of the facts previously presented are summarized in Table VII.

In reviewing the structural data on the several fault fields the following facts claim attention.

1. The average dip of the fault plane is between 40° and 50° toward the west. For a vertical displacement of 500 feet this would represent a horizontal displacement, that is, actual widening of the land surface at right angles to the fault, of about 500 feet.

2. As a consequence of this relatively low westward dip, wells drilled in the vicinity of these faults encountered differing conditions of stratigraphic thickness, as illustrated in the diagram (Fig. 29). Here the displacement is assumed to be somewhat greater than the thickness of the Austin chalk. With a displacement less than the chalk thickness there would be some overlap of the western end of the upthrown chalk and the eastern end of the downthrown chalk.

3. In a traverse section of any one of these structures the dip of the fault varies between extreme limits of 63° and 16°, generally becoming steeper in the resistant Austin chalk, less steep in the soft Eagle Ford shale, and again steeper in the Woodbine formation (Fig. 30). On the basis of these facts we should expect these faults to have rather steep dips in the hard Lower Cretaceous section.

4. Toward the ends of several of the fields there is a tendency for the fault surface to assume a steeper dip (Powell, North Currie, Wortham), or for the main fault to branch (South Groesbeck, Mexia, north-end Powell). The most exaggerated example of these conditions is seen at the south end of the Mexia structure, where there seems to be an overturning of the fault surface.

5. Where studies have been made of the folding at several horizons in any of these fields the axis of the fold in a particular stratum is found to lie not far east of the intersection of the fault with this stratum. Therefore, since, at every horizon, the fault has a low westward dip, the axis of the fold shifts westward with increasing depth in the formations. This indicates a definite genetic relationship between the folding and the faulting.

6. The large folds (Mexia, Powell) are asymmetrical, the steeper side dipping into the fault plane (westward).

TABLE VII

SUMMARY OF DATA ON STRUCTURE

Pool	Length in Feet	Maximum Width in Feet	Producing Acres	Original Eastern Oil-Water Contact in Feet Below Sea-Level*	Crest of Structure in Feet Below Sea-Level	Total Structural Relief of Pool, in Feet	Maximum Relief in Any Transverse Section, in Feet	Maximum Fault Displacement in Midway, in Feet	Maximum Fault Displacement in Chalk and Woodbine, in Feet
South Groesbeck	8,000±	3,500±	379	2,470?	2,415	55±	?	?	400
North Groesbeck	5,000±	2,500±	329	2,495	2,445	50	?	?	400
Mexia	36,000	7,000	2,880	2,480–2,530	2,355	175	130	260–300	550
Wortham	20,000	2,000	750	2,520–2,560	2,490	70	40–45	?	600–650
Currie	11,000	3,000	420	2,510–2,560	2,500	60	40	?	450–500
North Currie	9,000	2,000	370	2,580	2,535	45	40–45(?)	365–400	395
Richland	7,500	1,800	235	2,615–2,625	2,585	40	30	?	450–500
Powell	40,000	4,000	2,650	2,560–2,600	2,420	180	140	?	650
Nigger Creek	7,600	1,500	175	2,355–2,360	2,312	45	40	200	500
Cedar Creek	1,500+	800±	35±	2,385	2,373	12	....	....	450±

* See pp. 361–367. This column is inserted here for comparison with the structural data.

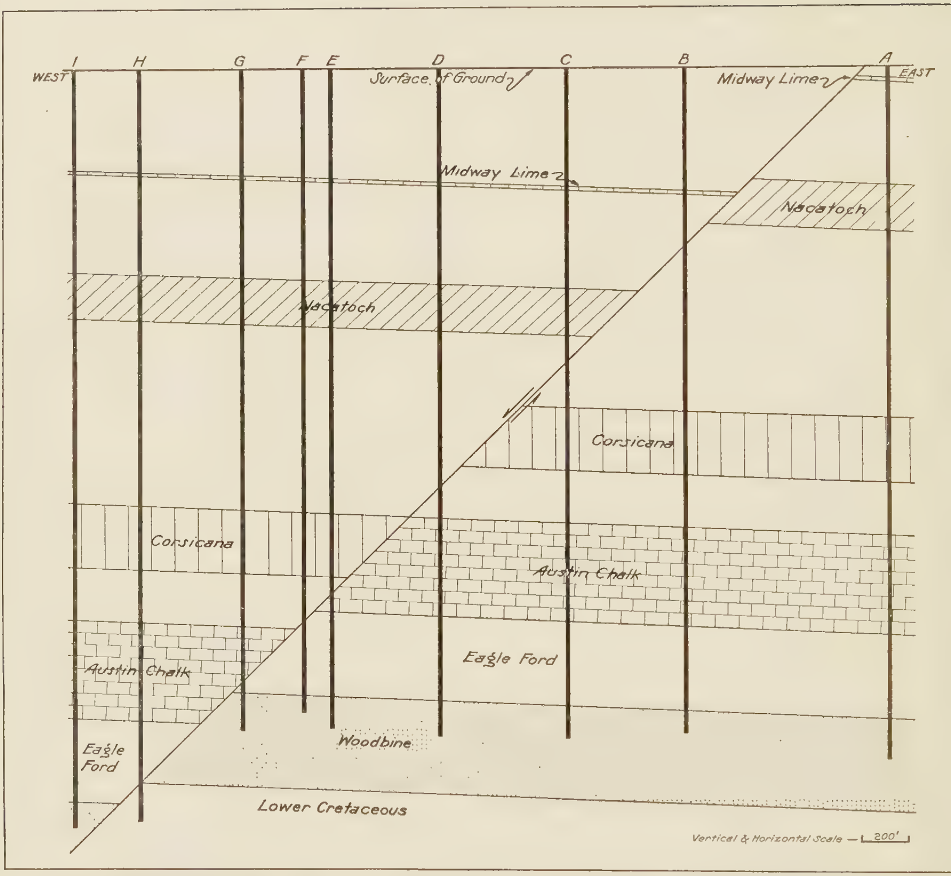


FIG. 29. Diagrammatic section to illustrate relations of wells to formations in different positio in the fault zone. The section is drawn to natural scale. The fault dip is about the average for t several faults in the Mexia zone, and the thicknesses of formations are approximately correct drawn. Well *A* encounters a normal section, upthrown, and well *I* a normal downthrown section dow to at least 200 feet into the Woodbine. Well *B* gets downthrown Midway lime and upthrown Corsica sand, with a reduction in interval between these two formations equal to the throw of the fault (he about 500 feet). In like manner, wells *C* to *H* encounter some formations upthrown and some dow thrown, with consequent reductions in interval. These can be ascertained by studying the sectio Notice that in some wells, as *B*, *D*, *F*, and *H*, certain formations would be missing in the log (here, respe tively, the Nacatoch, Corsicana, Austin chalk, and Woodbine). Scale in feet.

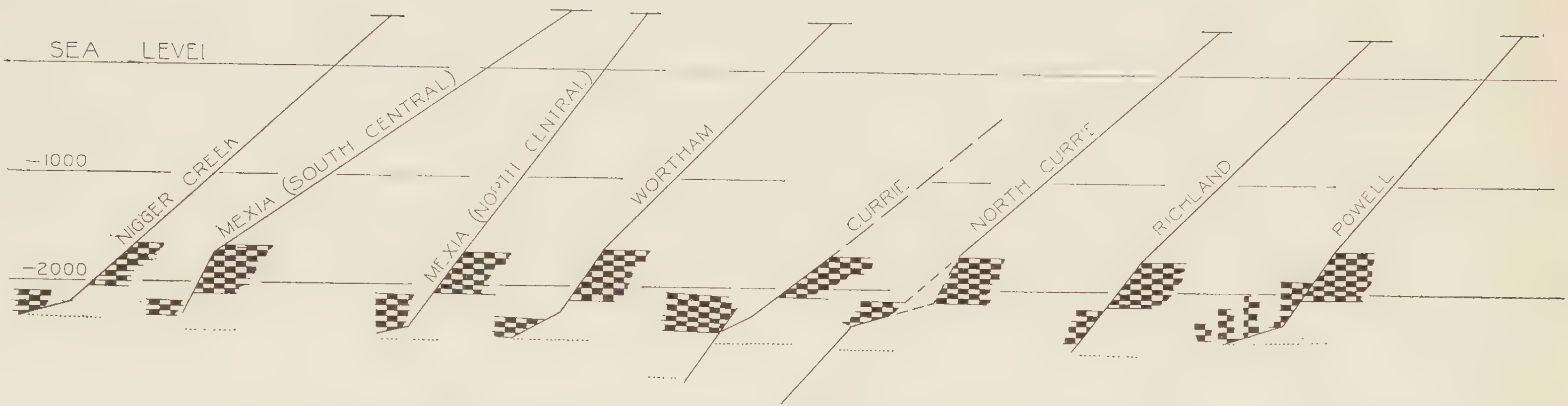


FIG. 30.—Comparison of the fault dips in the Mexia zone. The dips are drawn to natural scale, corrected to a position in a plane at right angles to strike. Brick pattern, Austin chalk. Dotted line, top of Woodbine. Horizontal line at upper end of fault line, surface of ground.

7. The better developed folds (Mexia, Wortham, Powell) are broadest and highest near places where the fault intersection with the Woodbine "pay" makes a bend convex westward, and generally where the fault has its least average angle of inclination.

8. The displacement of the major fault seems to be at a maximum in the middle part of each field, with a decrease in the throw toward the extremities.

9. The displacement in the Midway is in some cases about equal to that in the Cretaceous (North Currie), and in others much less than in the Cretaceous (Mexia, Nigger Creek). Where the latter is the condition, some displacement must have been accomplished before the Midway was laid down, and the remainder of the movement, after Midway and Wilcox time; but where the displacement is the same in Midway and Cretaceous, practically all the movement must have been post-Midway, and probably post-Wilcox (p. 351). It is unfortunate that there are satisfactory data on this relationship from so few of the fields.

Figure 2 shows a very conspicuous habit displayed in the orientation and relationship of the oil-field structures. The trend of every pool is a little more northeast and southwest than the trend of the zone containing them all. The North Currie field alone might be offered as an exception, but actually it follows the rule of all these fields, that each is so oriented that if it were extended it would overlap, on the west, the north end of the field next south of it. However, the *folds* do not overlap one another, or, to put it differently, the *pools* do not overlap one another. To decide conclusively whether or not the *faults* overlap is difficult without core drilling designed to settle the problem. We have seen the relation between the North Currie and Richland faults (p. 346). Subsurface information from deep wells indicates that the Powell fault turns east of south at its south end, but we cannot ascertain just how it meets the Richland fault, if, indeed, they do meet. Similarly, well logs strongly suggest a bending of the Currie fault somewhat east of south, so as almost to reach the north end of the Wortham fault. In cases like these there are strong reasons, from geophysical data, for believing that these faults, like the Mexia fault, branch southward, the east branch being that suggested by the well logs (Fig. 2) and the west branch continuing southward, behind or west of the next field south. Not having sufficient information in hand, the writer has not shown this southward splitting of the faults in Figure 2, except on the Mexia structure.

The North Currie fault is distinct from the Currie fault. So, too, the

Groesbeck faults are definitely separate, and the North Groesbeck fault is probably not an extension of the main Mexia fault.

The Tehuacana zone of faulting, in which are the Nigger Creek and Cedar Creek structures, again, is characterized by this same habit of overlap (Fig. 2). North of the Nigger Creek fault and south of the Cedar Creek fault are other displacements of similar kind and manner of occurrence.

Another feature not yet mentioned is the close parallelism between these fault zones (Mexia and Tehuacana, and also Balcones) and the strike of the formations, especially the Eocene formations. This parallelism continues eastward through Kaufman, Hunt, and Hopkins counties. Clearly there is a genetic relationship between the development of the East Texas geosynclinal basin and the Mexia and Tehuacana fault zones, and, further, all the individual faults in these zones were the result of one regional force or system of forces. With all these facts before us it seems obvious that the Mexia and Tehuacana fault systems were produced by torsional forces involved in the settling of the east Texas geosyncline, torsional forces which were such that they could be resolved into tension approximately perpendicular to the trend of these fault zones and compression approximately normal to the tension. The writer believes that, while there may have been some drag occasioned by this faulting, the main folding associated with the faults is due to the compressional forces involved in the general torsion. The folds and the associated major faults were contemporaneous.

PRODUCING SANDS AND PRODUCTION DATA

PRODUCING DATA FOR PAY SANDS ABOVE THE WOODBINE FORMATION

For purposes of comparison a few words will be said here in regard to the shallow oil and gas pools in the Mexia fault zone and near this zone in Limestone, Freestone, and Navarro counties. The writer has no intention of submitting all the data available on these pools. For further information, see especially papers by Matson and Hopkins.[1]

1. *Mexia and Groesbeck district.*—On the Mexia and Groesbeck structures, as previously pointed out (p. 307), gas was produced from the Nacatoch sand for many years prior to the Woodbine oil discovery. The subsurface structure of the gas "pay" is shown in Figure 3. In 1915 the open-flow capacity of the whole Mexia-Groesbeck shallow field was ap-

[1] G. C. Matson, "Gas Prospects South and Southeast of Dallas," *U. S. Geol. Survey Bull. 629* (1916), p. 88. G. C. Matson and O. B. Hopkins, "The Corsicana Oil and Gas Field, Texas," *U. S. Geol. Survey Bull. 661* (1917), pp. 211–52.

proximately 220,000,000 cubic feet per day. The rock pressure at Mexia, when the pool was opened, was 276 pounds per square inch. The main gas sand was encountered at depths from 680 to 750 feet below the surface.

2. *Currie district.*—No shallow oil pool has been found associated with the Currie structure, although a few small wells were completed west of the present Woodbine pool.

3. *North Currie district.*—Southwest of the North Currie pool several old shallow wells had small quantities of oil or gas. All of these were on the downthrown side of the major fault. Gas was encountered at depths between 1,000 and 1,200 feet, and in some wells a little oil was found in sand just below the Midway limestone or possibly, in one or two wells, in porous sandy streaks within this limestone. This oil came from depths between 350 and 390 feet. The gas, from depths between 1,000 and 1,200 feet, probably originated in the downthrown Nacatoch sand zone.

In more recent drilling, in a shallow test hole on the A. M. Swink lease (Fig. 7), a showing of gas was found at 335 feet in a sandy shale break in the Midway; and in the Ernest Swink No. AD1 diamond hole a showing of heavy oil occurred at 345 feet in Midway glauconitic sand just under the Midway lime. At the present time Dickson is pumping a little heavy oil (gravity 20.3° Bé.) from the two wells on the Tucker land (Fig. 7). This comes from glauconitic sand at 368 feet below the surface. On the Ernest Swink "A" lease, also, showings of gas were reported from the upper part of the downthrown Nacatoch at 810 feet (Sun Oil Company's E. Swink No. A1).

Close to the North Currie fault, on its upthrow side, in the upper Nacatoch sand, Seay-Cranfill's West No. 1 had a gas blowout at 600 feet; and across the line toward the north the Sun Oil Company's diamond test, Hardy No. D1, was a small gasser at 547 feet. It had an initial flow of 260,000 cubic feet with a rock pressure of 170 pounds. A month after it was completed it had a daily capacity of 213,000 cubic feet, and two months after its completion this had decreased to 73,000 cubic feet per day.

4. *Powell and Corsicana district.*—The writer has previously called attention to some of the shallow pools which were producing oil or gas before the Woodbine "pay" was discovered at Powell (p. 317). There were altogether ten or twelve of these pools (Fig. 31). They have been described by Matson and Hopkins in the paper previously cited. In order to shorten the discussion of them here, the data pertaining to them are simply tabulated (Table VIII).

In the rush of drilling for the Woodbine "pay" during the intensive

development of the Powell field shallow pay sands were passed through and cased off. Later, after the Woodbine production declined, wells were drilled to test zones where showings had been found in the deeper holes.

FIG. 31.—Outline map of part of Navarro County, Texas, showing the relative positions of the shallow pools, producing from sands above the Austin chalk. The old shallow pools are cross-hatched horizontally; the new shallow pool (A to E), discovered since the Powell field was opened, are indicated by close diagonal lines; and the Powell field, producing from the Woodbine, is shown by vertical cross-hatching. The positions of the Powell fault and the fault northeast of the town of Powell are shown where they intersect the Woodbine. The fault line shown northwest of the Mildred pool is approximately the location of a surface fault. Scale in feet.

As a result, several areas of shallow production were opened. The most important of these is the area of the Kent and Smith leases (A, Fig. 31), where oil has been obtained from the Corsicana sand zone on the upthrown side of the Powell fault at depths between 1,475 and 1,650 feet.

From this pool southwestward to *B*, Figure 31, scattered wells indicate that production will be continuous from this "pay" between *A* and *B*. The average initial yield for more than 100 shallow wells in this belt was 30 barrels per day.

TABLE VIII

SHALLOW POOLS IN CORSICANA-POWELL DISTRICT DISCOVERED PRIOR TO 1923

Name	Producing Chiefly	Pay Sand	Depth to Pay (in Feet)	Gravity of Oil (in °Bé.)	Relation to Powell Fault
North Corsicana...	Oil	Corsicana	900–1,000	38.4	No close relation
South Corsicana...	Oil	Corsicana	1,000–1,200	37.9–38.6	No close relation
Edens............	Gas	Edens	....	......	Downthrown side
Mildred..........	Oil	Nacatoch Corsicana	800–850 1,600?	22.8 37.0	No close relation
Clements-Buchanan	Oil	Nacatoch	....	......	No close relation
White............	Oil	Nacatoch?	....	......	No close relation
Combest..........	Oil and gas	Nacatoch?	900–1,000	......	Downthrown side
Burke............	Oil	Nacatoch	850–950	21.35–23.1	Downthrown side
Witherspoon-McKie	Gas and oil	Nacatoch	850–1,000	......	Downthrown side

In the small areas, *C*, *D*, and *E* (Fig. 31), freakish and spotted production was obtained in several wells from the Nacatoch sand zone between 850 and 1,300 feet, and in pool *E*, one well, the Halmack Oil Company's Harvard No. 5, produced oil from the Corsicana sand zone at 1,780–1,810 feet. In these three pools (*C*, *D*, and *E*), both the Nacatoch

TABLE IX

SHALLOW POOLS IN POWELL DISTRICT DISCOVERED SINCE 1923

Designation in Fig. 31	Producing Chiefly	Pay Sand	Depth to Pay (in Feet)	Gravity of Oil (in °Bé.)	Relation to Powell Fault
A......	Oil	Corsicana	1,475–1,650	35.8	Upthrown side
B......	Oil	Corsicana	1,600	?	Upthrown side
C......	Oil, small	Nacatoch	1,030–1,300	?	Downthrown side
D......	Oil	Nacatoch	1,200	?	Downthrown side
E......	Oil and gas	Nacatoch Corsicana?	850–1,010 1,780–1,810	29.3–31.1 33.05	Downthrown side Downthrown side

and Corsicana sands are on the downthrown side of the Powell fault. A summary for pools *A* to *E* is shown in Table IX.

An interesting well was drilled by the Humble Oil and Refining Company on their S. D. Ramsey B lease (near the middle of the west side of the field, Fig. 8). This was their No. 30, which made an initial yield of

3,472 barrels for the first 24 hours. The oil was reported from a sand at 2,034–2,044 feet. Offsets on the south and east failed to pick up this sand, now thought to be the Corsicana sand on the downthrown side of the fault. The E. L. Smith Cerf No. 1A, when shot at 2,200 feet, started producing oil probably from the downthrown Corsicana sand.

5. *Richland district.*—No oil or gas production has yet been obtained from sands above the Austin chalk in the area of the Richland fault, although several wells, for example, the Sun Oil Company's Brown No. 10 and No. 11, have reported showings from the Nacatoch horizon on the downthrown side of the fault.

6. *Wortham district.*—Reference to the shallow gas found in two or three wells at Wortham was made under "History" (pp. 319–321). During the development of the Woodbine "pay," shallow production was discovered in several localities, but in no place did this lead to commercial pools. At the north end of the field, in the Wortham Townsite (Fig. 11), Mike Kouri completed an oil well at 1,185 feet in the Nacatoch sand on the downthrown side of the fault.

Near the southern end of the field the Pure Oil Company, on what was originally the Boyd Oil Company's Boyd lease, finished two shallow wells, No. 23S and No. 25S, making oil from the downthrown Nacatoch sand at 1,375–1,400 feet. Boyd No. 25S was the discovery well, with 60 barrels of oil initial yield, with some water. Several deep wells in this vicinity had very good oil showings when they were drilled through this zone.

On the upthrown side of the Wortham fault rather strong gas (6,000,000–7,000,000 cubic feet initial yield) was encountered in several wells in a sand between 600 and 675 feet (Fig. 11), about 1,600 feet above the Austin chalk, the same interval that separates the Austin chalk and the 600-foot gas sand on the east side of the North Currie structure. The writer believes that this is probably upthrown Nacatoch sand, although Hill and Sutton have described it as an unnamed sand above the Nacatoch.[1]

7. *Nigger Creek and Cedar Creek.*—No production has been obtained from sands above the Woodbine formation in the Nigger Creek and Cedar Creek "back-fault" fields.

PRODUCTION DATA FOR PAY SANDS WITHIN THE WOODBINE FORMATION

1. *Mexia field.*—Students of conditions in the Mexia field subdivide the upper part of the Woodbine, in which are situated the main "pays," into five zones, separated by shale breaks, shown in Table X.

[1] H. B. Hill and C. E. Sutton, "Petroleum Engineering in Wortham Oil Field, Limestone and Freestone Counties, Texas," *U. S. Bureau of Mines* (April, 1927), p. 6.

The thicknesses given are average figures. Actually there is much variation in the thicknesses reported in different parts of the field. In most wells probably the top of the "main pay" may be regarded as the top of the second zone. In many wells no discrimination was made as to separation into zones.

About 230–50 feet below the top of the Woodbine formation and 200–220 feet below the top of the "main pay" is a deeper producing sand, called the "Kollman pay," since it was discovered on the Kollman land. Only a small proportion of the Mexia field has produced oil from this "pay" (Fig. 4). This is partly because it has not been found commercially successful in some tests, but perhaps more for the reason that relatively few wells have been drilled into it.

TABLE X

Subdivisions		Thickness in Feet	
First zone.....	Top of Woodbine formation to first shale break	30	Practically barren sandy shale
First break....	Shale....................	5–6	
Second zone...	Sandy shale and sand	25	Small production; no water
Second break..	Shale	4–5	
Third zone....	Sand and some sandy shale	25	Considerable oil and water
Third break...	Shale....................	7–8	
Fourth zone...	Sand and some sandy shale	26–27	Good oil and considerable water
Fourth break..	Shale	2–4	
Fifth zone.....	Sand and sandy shale	25+	Good oil and large volume of water

Oil in the Mexia field was at first produced under high gas pressure. Some initial productions were as much as 25,000 barrels per day, although the average was, of course, much less. Oil from the main pay zone had an average gravity between 36° and 37° Bé. The Kollman oil was about 33.7° Bé.

The original eastern oil-and-water contact in the main pay sand lay between 2,480 and 2,530 feet below sea-level (Table VII). It was higher opposite the middle part of the pool than at the two ends. Since the crest of the fold in the pay sand is about 2,355 feet below sea-level, the oil-bearing part of the structure or the "pool," had a total structural relief of 175 feet. The areal extent of this pool is about 2,880 acres.

2. *Groesbeck fields.*—In the Groesbeck fields gas has been the principal product from the Woodbine. Oil was obtained in the Pure Oil Company's Stockton wells No. 1 and No. 2, both of which are situated be-

tween two faults. They are not on the main South Groesbeck structure (Fig. 17). The pay sand is from 15 to 30 feet below the top of the Woodbine formation.

The producing relief of the main Woodbine "pay" in the north pool is about 50 feet, and that in the south pool is about 55 feet. The north pool has an area of 330 acres, and the south pool covers 380 acres.

3. *Currie field*.—In the Currie field[1] the main pay sand ranged from 30 to 75 feet below the top of the Woodbine formation. Detailed studies of the Woodbine section have not been made. Several wells were brought in as gas wells, later producing oil; others produced both gas and oil at the start; and, lower on the structure, some produced chiefly oil. Some of the wells had initial yields of several thousand barrels daily. Most of the wells have yielded water, either soon after completion or along with the oil or gas from the beginning. While there was at first considerable speculation as to the source of this water, it was rather definitely proved to come from below the oil "pay." The principal gas "pay" was above the oil "pay," separated from it by several feet of shale.

The gravity of the main Woodbine oil was between 40.8° and 42.5° Bé., and that of the oil from the Morrow "pay" was about 42° Bé.

The oil-water contact in the main "pay" was between 2,510 and 2,560 feet below sea-level, being lowest on the anticlinal axis at the two ends of the field, and highest in the middle of the east flank of the fold and in the synclinal embayment at the south end. The total structural relief of the pool was 60 feet, the maximum relief in any transverse section being 40 feet. The horizontal area of the pool approximates 420 acres.

4. *North Currie field*.—In the North Currie field the top of the Woodbine is ordinarily marked by a hard thin limy sandstone. Below this are several zones, as shown in Table XI.

The first and second pay zones yielded oil at the north and south ends of the structure, and gas in the higher central part. Oil from the first zone has a gravity varying from 42° to 45° Bé., and that from the second is 38° Bé. The Swink "pay," which is 80 to 85 feet below the top of the Woodbine formation, yields oil with a gravity of 38.7° Bé.

Barclay and Meadows, in their Hilburn No. 4, cored oil sand at 3,200

[1] F. H. Lahee, "The Currie Field, Navarro County, Texas," *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 7 (1923), pp. 25–36; and "Further Notes on the Origin and Nature of the Currie Structure, Navarro County, Texas," *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), pp. 61–71.

feet, 255 feet below the top of the Woodbine, but several tests drilled down to this sand have failed to obtain commercial production from it.

The original eastern water level was approximately as shown by the dotted line in Figure 20. In September, 1925, water in the first "pay" was found at 2,587 feet, and in the second "pay" at 2,596 feet, below

TABLE XI

Zone	Thickness in Feet	
Top of Woodbine to top first pay	37	Alternating shales, sandy shales, and thin sands and limes. Small showings of oil or gas
First break	1–3	Lime shell
First pay	3–10	Sand producing dry gas. Initial yield 1,000,000–3,000,000 feet per day, or 50–150 barrels of oil
Second break	7–10	Shale and sandy shale
Second ("main") pay	16–20	Hard and soft sand with a few thin shale layers. Initial yields up to 20,000,000 cubic feet of gas per day, or 50–200 barrels of oil
Third break	10–12	Shale
Third ("Swink") pay	3–6	Thin sand yielding oil, up to 500 barrels initial

sea-level. The total structural relief for the pool was about 55 feet. The area is about 370 acres.

5. *Powell field.*—General production data for the Powell field have been summarized by H. B. Hill and C. E. Sutton.[1] Some of the wells had an initial yield as high as 25,000 barrels per day. The upper part of the Woodbine, according to Hill and Sutton, is divisible as follows:

Division		Thickness (in Feet)
Cap rock (top of Woodbine)		2–3
Barren zone, sandy shale and shale		25–30
Main pay	First pay (A)	22–25
	First break	1–2
	Second pay (B)	34–35
	Second break	2–4
	Third pay (C)	25–30
	Third break	35–37
	Fourth ("Big") pay (D)	?

[1] "Summarized Engineering Report on the Powell Field, Navarro County, Texas . . . . ," *Petroleum Development and Technology in 1926*, published by the *Amer. Inst. Min. and Met. Eng.*, 1927.

The Fourth "pay" or "Big pay" produced only locally at the highest part of the structure. The "Big pay" pool had an area of about 50 acres.

No production has been obtained at Powell from a sand corresponding to the Kollman "pay" at Mexia and the Morrow "pay" at Currie. Four wells have been drilled below the main "pay," as follows:

	Feet
Pure Oil Company's McKie No. 65	to 3,142
Gulf Company's McKie No. 3	to 3,125
Humphrey's (Pure) McKie No. 37	to 3,148
McMan Chapman No. 8	to 4,850

The original eastern oil-water contact in the main "pay" lay between 2,560 and 2,580 feet below sea-level in the south-central part of the field, but reached as low as −2,600 feet in the north end of the pool. The total structural relief for the pool was 180 feet, although the maximum relief in any one transverse section was only 140 feet. The pool has an extent of 2,650 acres. From a study of many wells, Hill and Sutton[1] found that the surface of contact between the oil above and the water below had a very low inclination, about 1 foot in 128, toward the east, away from the fault. This is a lower angle than the eastward dip of the strata, which is about 1 foot in 24 feet. In other words, the oil-water surface intersected the several pay sands of the structure.

In the same report these authors state that the biggest wells were those drilled deep enough to be close to bottom water (the oil-water surface previously cited). Water pressure forced oil into the hole and the gas served as a lifting force. The large wells were not necessarily on the high parts of the structure.

The gravity of the Woodbine oil at Wortham was between 39.5° and 39.7° Bé.

6. *Richland field.*—Studies in the Richland field indicate the presence of three pay zones in the upper Woodbine. The top of the Woodbine is marked by a hard thin lime break, about 1 foot thick. Below this is the upper pay zone, 18–23 feet thick, consisting of sandy shale with a few thin sand streaks, which may carry a little oil. Between this zone and the second "pay" is a break of lime and shale, ranging in thickness from 1 foot to 3 feet. The second "pay" is sand with shale breaks. This is the "main pay" which produced in a majority of the wells in the field. By pumping or swabbing such wells made from 300 to 500 barrels per day. A hard limy sand, 3–7 feet thick, serves as a break between the

[1] *Op. cit.*

second and third zones. The third "pay" is a soft sand which has been penetrated only a few feet in several wells. Wells in this "pay" had initial yields of as much as 2,500 barrels per day flowing. This field had less gas pressure than any of the Mexia zone pools in the Woodbine "pay."

No wells in the Richland field have tested the Morrow pay horizon.

The gravity of the oil was 37.9° Bé. The original oil-water contact was between 2,615 and 2,625 feet below sea-level. It was lower at the two ends of the structure. The total structural relief of the pool in the Woodbine "pay" was only 40 feet, the maximum relief in any one transverse section being 30 feet. The area of the pool is 235 acres.

7. *Wortham field.*—According to the Bureau of Mines,[1] oil in the Wortham field came from two pay zones, which were designated *A* and *B*, separated by a shale break. Above the upper zone, *A*, is 15–25 feet of sandy shale with thin sandy layers, some of which carried showings of oil. Above this is a hard "shell" near or at the top of the Woodbine formation. Sand *A* is 20–22 feet thick. In it big flowing wells were brought in near the east edge of the field. Higher on the structure, nearer the fault, big wells were completed in *B*, but here wells in *A* did not flow.

Initial productions at Wortham ran as high as 10,000 barrels. In the early days of the field there was considerable gas pressure. The oil gravity was 39.5–39.7° Bé.

Several wells were drilled below the main Woodbine "pay" without discovering commercial production at the horizon of the Kollman pay. These were:

	Depth Drilled (in Feet)
H. & T. C. Right of Way No. 14	4,830
So. Exploration Co.'s Longbotham No. 1	3,265
Pure Oil Co.'s Gus Pierce No. 1	3,167
Hoosier *et al.* Stubbs No. 1	3,145
Magnolia Co.'s Boyd No. 14	3,200

The original oil-water contact on the east of the field coincided approximately with the −2,520-foot contour on the Woodbine pay sand, near the middle of the pool, descending to −2,540 feet at the north end, and to −2,560 feet at the south end, of the field (Fig. 27). The total structural relief of the pool was 70 feet, but the maximum relief in any transverse section was nowhere more than 40 or 45 feet. The Wortham field has an extent of 750 acres. As in the Powell field, the oil-water sur-

[1] H. B. Hill and Charles E. Sutton, "Petroleum Engineering in the Wortham Oil Field, Limestone and Freestone Counties, Texas," *U. S. Bureau of Mines*, April, 1927.

face was found to have a very gentle eastward inclination, being a few feet higher at the fault than on the east side of the pool. It was nearly the same in the two pay zones, *A* and *B*.

8. *Nigger Creek.*—The Nigger Creek field is only 7,600 feet long and 1,500 feet wide. The original oil-water contact was at −2,360 feet. The area of this pool is about 175 acres. Its structural relief is 45 feet. The gravity of the oil varies from 37.21° Bé. to more than 40° Bé. Tests of the pay sand indicated a porosity of 25 per cent, a figure which is probably fairly representative for the main prolific Woodbine "pays" of the pools in the Mexia zone.

9. *Cedar Creek.*—The outlines of this small pool have not yet been fully defined. The gravity of the oil varies from 35.5° to 38.1° Bé.

PRODUCTION DATA FOR PAY SANDS BELOW THE WOODBINE FORMATION

Very little can now be said with reference to the subject of pay sands below the Woodbine formation. On the Mexia structure, E. L. Smith, on the Steubenrauch land (Fig. 4), discovered some gas and oil in a sand at 5,732 feet, which may be in the basal part of the Glen Rose formation or in the top of the Travis Peak. The oil had a gravity of 39° Bé. This production has encouraged the drilling of another test a few hundred feet farther west, but in this well, drilling has only just commenced.

The Sun Oil Company's H. A. Swink No. C1 had showings of oil in the Glen Rose at depths of 4,843, 5,186, and 5,265 feet. The oil from 5,186 feet had a gravity of 32.5° Bé. This hole was lost at 5,412 feet, approximately 100 feet stratigraphically above the oil sand at the bottom of the Steubenrauch well.

Comparison of oil gravities.—Table XII shows the gravities of oils from the different pay sands in or near the Mexia fault zone fields.

In Table XII the writer wishes to call particular attention to the following facts:

1. The gravity of the Midway oil is low and the paraffin content is low, both features characteristic of the Nacatoch oil on the downthrown side of the faults associated with the Wortham and Burke (north Powell) fields. Since the Midway basal sand is not normally oil-bearing in this district, may not this mean that this oil has come up the North Currie fault, or an associated fault?

2. The Nacatoch oil from the downthrown side of the Mildred and south Powell faults has a higher gravity and paraffin content than the Nacatoch oil from the Wortham and Burke pools.

3. The Nacatoch sand yields gas on the upthrown side of the faults

TABLE XII

OIL GRAVITIES*

Pay Sand	Well or Field	Approximate Depth (in Feet)	Relation to Main Fault	Gravity in Degrees, Bé.	Percentage of Paraffin
Midway	Dickson Wells SW. of North Currie field	370	Downthrown side of North Currie Fault	20.3	.13
Nacatoch	Mildred pool	800–850	Downthrown side of Mildred Fault with drop on E.	29.25	.94
Nacatoch	Powell (north) (Burke)	800–850	Downthrown	21.35	.15
Nacatoch	Powell (south) (Field "E")	1,000	Downthrown	29.3–31.1	1.44–1.69
Nacatoch	Wortham (north end)	1,185–90	Downthrown	21.1	.19
Nacatoch	Wortham (south end)	1,276–84	Downthrown	21.8	1.51
Corsicana	So. Corsicana	1,100–1,150		37.9	2.36–2.38
Corsicana	Powell, field A	1,500	Upthrown	35.8	1.75
Main Woodbine	Powell north end	2,850–2,950	Upthrown	27.8–34.6	1.31–2.00
Main Woodbine	Powell central	2,830–2,950	Upthrown	37.1–38.1	1.45–1.65
Main Woodbine	Powell south end	2,850–2,980	Upthrown	35.6–38.6	1.6 –1.82
Main Woodbine	Richland	2,900–2,950	Upthrown	37.9	1.56
Upper Main Woodbine pay	North Currie	2,940–2,960	Upthrown	42.33–45	1.15–2.00
Lower Main Woodbine pay	North Currie	2,970–3,000	Upthrown	38.5–39	1.24–1.73
Swink	North Currie	3,000–3,020	Upthrown	38.5–38.9	1.32–1.63
Main Woodbine	Currie	2,925–2,975	Upthrown	40.8–42.5	1.39–1.54
Main Woodbine	Wortham	2,930–3,000	Upthrown	39.5–39.7	1.32–1.51
					2.06–2.14
Main Woodbine	Mexia, E. edge	3,000–3,075	Upthrown	35.62–36.07	1.72–2.84
Main Woodbine	Mexia, central	2,975–3,025	Upthrown	36.1–36.75	1.41–1.55
Main Woodbine	Mexia, west edge near fault	2,950–3,050	Upthrown	37.3–38.00	1.17–2.22
Main Woodbine	Nigger Creek	2,825–2,875	Upthrown	37.21–39.62	.58–1.03
Morrow	Currie	3,150–3,210	Upthrown	41.7–42.7	1.25–2.04
Kollman	Mexia	....	Upthrown	33.7–33.8	1.87–2.19
Show, Glen Rose	North Currie (H. A. Swink C1)	5,186	Upthrown	32.5	8.45
Lower Glen Rose	Mexia (Smith Steubenrauch 1)	5,732	Upthrown	39	6.82

* This table gives the results of about one hundred analyses of oils taken from scattered wells in the several fields.

at Groesbeck, Mexia, Wortham, and North Currie (a fact not cited in the table, but mentioned previously in this report). This suggests that the Nacatoch oil has migrated up faults from a lower source and has passed chiefly into the downthrown Nacatoch zone, only the lighter constituents continuing upward to the upthrown Nacatoch sand. Or, the conditions of accumulation or of migration may have been such as to produce gas on the upthrown, and oil on the downthrown, side of the fault, with retention of oil near the fault because of up-dip lensing of the sand. In any case it should be noticed that this Nacatoch oil is only in small amount, especially at Wortham.

4. The Corsicana sand yields a much lighter oil than that from the Nacatoch sand.

5. The principal Corsicana sand production is from the upthrown side of the Powell fault, and from pools some distance up the regionl dip from the Mexia zone faults (Mildred and North and South Corsicana).

6. There is a wide range of gravity in the oil from the main Woodbine pay zone, even in the same pools (see following). This range is from 27.8° at the north end of the Powell field to 45° in the North Currie pool. Nevertheless the paraffin content runs fairly constant, from 1.15 per cent to 2.14 per cent, not including the Nigger Creek oil.

7. The upper Woodbine main pay zone in the North Currie field carries oil of much lighter gravity than the lower main pay zone, only 10 feet deeper, yet both these sands yielded large volumes of gas in the upper part of the structure, and the lower zone produced the biggest volumes of gas. On the other hand, this lower main pay sand and the Swink "pay," only 35 feet apart, yielded oil of the same gravity and paraffin content, yet the Swink pay yielded no gas, or very little.

8. Omitting the Groesbeck gas fields, the average gravity of the oil for the several fields is lower in the larger pools, Mexia and Powell, at the two ends of the chain of structures; is highest in the two central pools (Currie and North Currie); and is intermediate in value in the Wortham and Richland pools. It is interesting to note that, just as the Groesbeck structures at the south end of the chain yield gas, so also gas was found in the Connor well drilled by the Boyd Oil Company on the fault structure next northeast of the Powell field.

9. The lower Woodbine oil, from the Kollman and Morrow "pays," does not differ very markedly from the upper Woodbine ("main pay") oil in the same field.

10. The Glen Rose oil has a much higher paraffin content than the Woodbine oils from the same structures.

The tests run on the Mexia field showed a higher gravity for oils on the western side of the pool, close to the fault, than near the middle or eastern parts of the pool.

More figures were available for Powell, where a much greater range of gravity was observed, than at Mexia. In Figure 32 are lines of equal oil gravity, showing that in general the oil had a higher gravity higher on the structure and nearer to the fault (compare Fig. 23).

These relations of gravity to structure point to the conclusion that, while the petroleum was accumulating on the structure, or since that time, it has undergone a certain amount of progressive alteration and redistribution according to gravity. There is a larger proportion of gas and lighter fractions present in the oil higher on the structure. This, of course, is to be expected. Gravity, then, is to some extent a local phenomenon, related to structure. The reader should notice that these conditions are found in a marked degree only on the two largest and most pronounced structures.

Some study has been made of gravity changes on certain leases during a long period of time. Briefly, only slight changes have been noticed. On some leases the gravity has increased, whereas on others it has decreased. The maximum fall of which we have a record in the Mexia field was from 36.2° to 33.9° Bé., between December, 1923, and January, 1927. The maximum rise was from 35.9° to 36.5° in the same interval. In the Wortham field the maximum recorded fall was from 39.3° to 38.0°, and the maximum rise was from 39.2° to 40.0°. The only definite fact brought out by this comparison is that the range of the Wood-

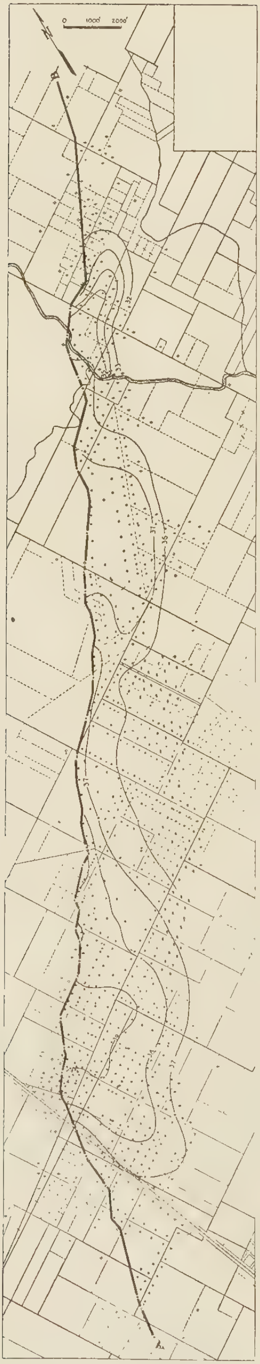


Fig. 32.—Map of the Powell field, showing the relations between the fault in the Woodbine (*AB*) and the variations in the gravity of the Woodbine oil. The contours represent lines of equal gravity in degrees Bé. Scale in feet.

bine oil gravities in both the Mexia and Wortham fields has increased with time. Thus, where on a certain group of leases in the Mexia field the range lay between 34.8° and 36.6° in December, 1923, the range on these same leases had increased from 33.9° to 36.5° in January, 1927; and between April, 1925, and January, 1927, the oil gravity range on a group of leases in the Wortham field increased from 39.0°–39.6° to 38.0°–40.3°.

WATER

Occurrence of water.—Throughout the region within which are situated the oil fields of the Mexia fault zone, the Woodbine formation carries water. In association with the oil fields this water is found as edge water in the sand zones which produce the oil, or as bottom water below the oil in the area of the pools. There was little, if any, top water encountered above the main pay zone below the top of the Woodbine. In some wells bottom water in the main pay zone was found in the areas of production from the Kollman or Morrow "pay."

Fluid levels.—Some of the sandstone beds of the Woodbine are fine grained and of uneven grain, with more or less mixed shaly and lignitic material, whereas other beds are very porous, rather coarse-grained and of fairly uniform grain. When wells in the several fields were drilled into one or another of the pay sands the fluid from the sand—water, or oil, or oil and water, as the case might be—was found to rise in the casing to different levels above the bottom of the hole. The oil from the upper pay sand at Powell, Richland, and Wortham rose to heights between 200 and 600 feet above the bottom of the hole when this sand was permitted to yield its fluid without deeper drilling. When the drilling penetrated sands which lay between this upper "pay" and the deeper sands which made flowing wells, the oil rose to heights from 1,800 to 2,200 feet above the bottom of the hole at Richland; to heights between 1,100 and 1,600 feet for pay sands *B* and *C*, and, after the head was off, to 2,600 feet above the bottom of the hole for *D* (p. 364), at Powell; and to heights between 500 and 600 feet above the bottom of the hole for sand *A* at Wortham. These figures are for wells which were on the pump, the gas, if originally present, having ceased to flow.

Unfortunately very little systematic study was made of these fluid levels. They were observed early in the drilling of the pools, and they are thought still to persist, although perhaps with some minor modification. To some extent the differences were undoubtedly due to gas pressure and to rate of pumping of near-by wells, but these factors were merely incidental.[1] The main cause seems to have been related to the porosity

[1] This refers only to sands which did not yield flowing wells.

of the particular sand. Invariably the wells with low fluid level produced from fine-grained sands of rather uneven grain, as previously described, and the wells with a high fluid level yielded from coarser sands of more uniform grain, allowing more easy flow of the oil to the hole. The two or three sands controlling fluid levels differing by 1,500 feet or more are separated by relatively few feet of shale; therefore, they should exhibit approximately the same hydrostatic head. This upper part of the Woodbine is exposed at an average elevation of approximately 600 feet above sea-level, 50 or 60 miles west of the Mexia fault zone. The average elevation of the land in the fault zone is 500 feet above sea-level.

The foregoing information has been furnished, scant though it is, principally as a suggestion of a problem which deserves further investigation.

Composition variations in the upper Woodbine waters.—A most interesting and instructive subject is that bearing on the variations in composition of the waters of the Woodbine sands. If we eliminate from consideration the waters immediately associated with the major faults, and then make a comparison of the waters from the upper Woodbine sands, taken from wells at different points across the strike, we find that these waters exhibit, in a direction down the dip, a rather regular increase in total solid content, an increase in chlorides and sodium, a decrease in carbonates, and a decrease in sulphates, all these being expressed in parts per million by weight (PPM.). When stated in the terms proposed by Palmer,[1] these analyses show a down-dip increase in primary salinity and a down-dip decrease in secondary salinity and secondary alkalinity.

If the analyses are compared for waters secured from wells along the strike of the formations, roughly parallel to the chain of oil fields, particularly within a few miles east of the fields, they show, in a northward direction, a decrease in total solid content, a decrease in chlorides and sodium, an increase in carbonates, a decrease in primary salinity and secondary salinity, and a slight increase in secondary alkalinity.

These variations may be attributed chiefly to the mixing of meteoric waters with the original connate waters, a change which would obviously be progressively greater up the dip toward the Woodbine outcrop and toward the trough of the regional syncline, that is, northeastward along the strike.

[1] These terms were proposed by Chase Palmer in "Geochemical Interpretation of Water Analyses," *U. S. Geol. Survey Bull. 479* (1911), p. 12. See also, referring to their application to oil-field waters, "Geochemical Relations of the Oil, Gas and Water," in Part II of "The Sunset-Midway Oil Field," by R. W. Pack and G. Sherburne Rogers, *U. S. Geol. Survey Prof. Paper 117*, 1919.

In the vicinity of the Mexia zone faults there is a marked deviation from the normal conditions described. Waters from the Woodbine close to these faults, on the upthrown side, show abnormally high total solids, chlorides, and sodium, and occasionally relatively high sulphates and carbonates, as compared with Woodbine waters a little farther east.

At the time of the Houston meeting of the American Association of Petroleum Geologists, R. B. Whitehead read a paper,[1] prepared by himself and R. H. Fash, in which they discussed at some length conclusions which they had drawn from a study of the waters in the fault zone. They wrote as follows:

The waters occurring in the Woodbine sand in east Texas belong to the following types: altered connate, altered meteoric, and mixed. The altered connate water in general can be considered as lying east of the producing faulted zone. It is the water that occurred in the sand at the time it was deposited and which has been altered by the action of organic matter and zeolites. In addition to the above altered connate water, there is an altered brine occurring close to the fault, which its position would indicate was not indigenous to the Woodbine, but had come up the fault plane. In general, the modified meteoric water occurs west of the producing faulted area and is the water which enters at the outcrop of the Woodbine and has been altered by the organic matter present in the shale members and the zeolites in the sand. The mixed type consists of an admixture of the above waters, the degree of admixture depending upon the thoroughness of the fault seal. . . . .

At the outcrop, meteoric waters are entering the Woodbine sand and are migrating down dip through the action of gravity and capillary attraction to a certain critical level where they cease to be fresh. At Dallas the Woodbine sand, which is encountered at depths from 672 to 1,000 feet, contains a typical modified meteoric water, as indicated by the absence of secondary salinity, high primary alkalinity, and high ratio of carbonate to sulphate. . . . .

From theoretical considerations (Rogers), an altered sea water would have the following composition: Primary salinity, 85.4 per cent; secondary salinity, 12.8 per cent; secondary alkalinity, 1.8 per cent; total solids, 32,200 parts per million. . . . . When an altered sea water and a modified water mix, reactions occur between the dissolved constituents of the water which decrease the secondary salinity and increase the primary salinity. This can be expressed by the following equation:

$$\underset{\text{Secondary salinity}}{CaCl_2} + \underset{\text{Primary alkalinity}}{Na_2CO_3} = \underset{\text{Primary salinity}}{2\,NaCl} + \underset{\text{Secondary alkalinity}}{CaCO_3}$$

As a result, calcium carbonate is deposited. . . . .

[1] R. B. Whitehead and R. H. Fash, "A Study of the Application of Oil Field Water Analyses to the Fault Zone Type of Accumulation," 1924. (Not yet published.)

Analyses of waters at Currie, Richland, and Powell indicate that waters close to the fault are less mixed with meteoric water than waters farther away on either side of the fault. East of the fault and east of the zone of maximum admixture the water again becomes more of an altered brine type. The occurrence of a larger admixture of meteoric water east of the fault than occurs at the fault proper indicates that at some time brine had entered the Woodbine via the fault plane. . . . .

To be more specific with regard to the several fields, the Woodbine water analyses available to the writer reveal the following ranges in total solid content, in parts per million, by weight:

TABLE XIII

TOTAL SOLID CONTENT OF UPPER WOODBINE WATERS

Oil Field or Well	Position of Well in Field	Total Solid Content (in Parts per Million)
Mexia field	East edge, north end	30,375
	East edge, middle	31,449
	Average east edge	30,000–31,500
	Extreme south end	17,332
	West edge, middle	35,388–39,500
Nigger Creek	East edge, middle	26,500
	Middle of field	26,371–28,000
	West edge	26,100–27,340
Wortham	North end, near east edge	22,000
	South end, near east edge	23,315
	Average east edge	22,000–23,300
	Middle of field	23,169
	West edge, middle	24,379
Currie	East edge, middle	18,891
	West edge, middle	20,589
No. Currie	North extremity	12,770
	North end, east edge	12,972
	South end, east edge	19,280–21,000
	North end, west edge	14,000–14,500
	Middle, west edge	21,000
	South end, west edge	21,000
Richland	North end, east edge	13,500–13,750
	Middle, east edge	12,000–13,000
	North end, west edge	13,350
	Middle, west edge	15,500–16,700
Powell	East edge, middle	11,500–13,800
	East edge, south end	8,307
	West edge	16,000–19,000

TABLE XIII—*Continued*

SCATTERED WELLS

Well	Miles from Mexia Fault Zone	Total Solids (in Parts per Million)
Dallas water well	40 miles northwest (up-dip)	1,478
Corsicana Natatorium well	5 miles northwest (up-dip)	6,134
Mexia Oil Syndicate Sline No. 1	5½ miles northwest (up-dip)	8,172
Humphreys-Mexia Singleton No. 1	2½ miles southeast (down-dip)	14,773
New-way Cheney No. 1	1⅓ miles east (down-dip)	15,442
Kerens water well	3 miles southeast (down-dip)	25,804

Taking into consideration analyses of a relatively few waters (*a*) from wells within the producing areas or near their east edge, on the one hand, and (*b*) from wells close to the faults, on the other hand, we find ranges in composition as shown in Table XIV.

It is interesting to notice that some of the Woodbine water at Mexia has a solid content about the same as that of average sea water (35,000 PPM.); but the analyses show that this is only a coincidence. The Mexia waters, away from the fault, contain lower sulphates, lower magnesium, and higher carbonates or bicarbonates than sea water. For example, compare the following average analysis of seventy-seven samples of sea water, taken by the Challenger Expedition,[1] with the analyses given in Table XIII.

Comparison of waters from deeper Woodbine sands.—The only waters of which analyses are available from Woodbine sands below the main "pay" are from the North Currie field. A sample from the Sun Oil Company's H. A. Swink No. *A*2 showed 15,178 parts per million total solids from a sand 105 feet below the top of the Woodbine. During a series of plugging tests made by the Sun Oil Company on its H. A. Swink No. A1, analyses of waters from the following depths showed total solid contents as given in Table XVI.

No sulphates were found. The analysis which gave 15,850 parts per million for water from depths ranging from 2,992 feet to 3,022 feet was run on September 29, 1925. On November 20 of the same year the analysis of the water from this same range in depth showed 16,813 parts per million.

Water from the Swink "pay" at 3,016 feet in the Sun Oil Company's H. A. Swink No. A1 ran as shown in Table XVII.

[1] F. W. Clarke, "Data of Geochemistry," 5th ed., *U. S. Geol. Survey Bull. 770* (1924), p. 127.

TABLE XIV

COMPOSITION OF WOODBINE WATERS FROM THE FAULT FIELDS (EAST PART OF FIELD)

	Sodium		Calcium		Magnesium		Sulphates		Chlorides		Bicarbonates	
	PPM.*	Percentage RV.†	PPM.	Percentage RV.	PPM.	Percentage RV.	PPM.	Percentage RV.	PPM.	Percentage RV.	PPM.	Percentage RV.
Mexia	9,340–10,420	44.92–45.97	553–766	2.8–3.6	147–153	1.23–1.38	0	0	15,748–17,541	49.21–49.3	412–472	.70–.79
Nigger Creek	9,522–11,146	45.94–48.28	97–452	.48–2.51	146–174	1.24–1.57	0	0	15,720–17,534	49.27–49.36	315–448	.58–.73
Wortham	7,433–8,309	45.78–48.58	296.6–300.9	1.99–2.13	91.4–95.5	1.06	0	0	12,425–13,300	47.21–49.7	391–568	.88–1.32
North Currie	4,660‡	47.39‡	116.4‡	1.35‡	15.2‡	.23‡	0	0	7,335–11,552	47.76–48.56	508–644	1.25–2.47
Richland	4,880‡	53.11‡	83‡	.78‡	16‡	.32‡	0	0	6,125–8,315	43.33–47.78	597–758	2.26–2.96
Powell	3,231–5,319	47.1–47.5	0	0	94–148	1.9–2.9	6–57	.04–.25	4,574–7,286	41.79–43.26	600–1,104	6.7–7.95

COMPOSITION OF WOODBINE WATERS FROM WELLS NEAR THE FAULTS (WEST EDGE OF FIELD)

	Sodium		Calcium		Magnesium		Sulphates		Chlorides		Bicarbonates	
	PPM.*	Percentage RV.†	PPM.	Percentage RV.	PPM.	Percentage RV.	PPM.	Percentage RV.	PPM.	Percentage RV.	PPM.	Percentage RV.
Mexia‡	14,254	45.48	845	3.09	205	1.24	193	.29	23,930	49.54	268	.34
Nigger Creek	9,522–9,959	46.15–46.18	452–483	2.51–2.57	143–146	1.25–1.34	0	0	15,720–16,440	49.42–49.45	315	.55–.58
Wortham	8,027–9,384	46.02–48.71	222–293	1.32–1.77	79–103	.86–1.16	0	0	13,049–14,184	47.57–49.08	476–519	.97–1.13
North Currie	52,368‡	47.43‡	128.2‡	1.34‡	71.6‡	1.23‡	0–28.8	0–.12	8,100–11,440	47.60–48.56	328.8–690	1.37–2.28
Richland	5,246–5,613.8	47.75–48.25	107–142.8	1.07–1.43	21.6–48	.35–.82	0–51	0–.21	8,085–9,257	47.70–47.89	284–690	1.93–2.30
Powell	4,100–7,063	47.6–48.97	52–148	.71–1.25	10–66	.23–.80	0–28	0–.16	5,633–10,851	43.03–47.74	933–1,531	2.38–6.6

* PPM. = Parts per million, by weight.
† Percentage RV. = Percentage reacting value.
‡ These figures from one analysis only.

TABLE XV

AVERAGE ANALYSIS OF 77 SAMPLES OF SEA WATER

	Parts per Million	Percentage Reacting Value
Sodium	11,159	40.01
Calcium	421	1.32
Magnesium	1,310	8.87
Sulphates	2,450	4.2
Chlorides	19,519	45.39
Carbonates	0	0.0
Bicarbonates	70	0.19
Total solids	34,929	99.98

Primary salinity =80.02. Primary alkalinity =0.0.
Secondary salinity=19.18. Secondary alkalinity =0.80.

TABLE XVI

WATER ANALYSES FROM SWINK NO. A1

Source of Water Depth in Feet	Total Solids	Approx. Chlorides		Approx. Carbonates and Bicarbonates	
		PPM.*	Percentage RV.†	PPM.	Percentage RV.
3,057–3,183	15,000	8768	48.03	616	1.96
2,992–3,069	15,580	8974	48.09	612	1.91
2,997–3,022	15,850	8973	48.57	453	1.43
3,016	14,184	8072	....	....	....

* PPM.=Parts per million, in weight.

† Percentage RV.=Percentage reacting value.

TABLE XVII

	Sodium	Calcium	Magnesium	Sulphate	Chlorides	Bicarbonates
PPM	5241	153	40	0	8072	678
Percentage RV	47.71	1.60	.69	0	47.67	2.33

This water carried 14,184 parts per million total solids.

If the total solid content of the Woodbine waters from Dallas to Kerens be plotted against the distance between the wells, measured at right angles to the strike, the curve of eastward (down-dip) increase in total solids is fairly uniform, except near the fault, where it crosses the Powell field. Here there is a distinct break, but the abnormal *rise* of the

curve at the fault is much less pronounced than the abnormal *drop* in the curve in and just east of the field. In other words, while it is true that, in the oil fields, the Woodbine waters are more concentrated in dissolved salts near the faults than in the central and eastern parts of the fields, nevertheless the peculiar feature seems to be, not the relatively high concentration of the fault-line waters, but the relatively low concentration of the east edge and east bottom waters.

Another fact which seems to the writer conspicuous is the general similarity of the Woodbine waters in the oil fields and east of the fields (Table XIII), except as regards *amount* of dissolved substances. Whether the water came from the fault, or from the east edge of a field, or from an upper or lower member of the Woodbine, the proportion of the dissolved salts is rather close. Locally, in waters near the fault, there is a minor increase in sulphates and carbonates or bicarbonates, but this does not appear to be the rule.

Waters from the Lower Cretaceous.—Table XVIII shows a summarized analysis of several waters from wells drilled into the Lower Cretaceous formations.

In comparing these analyses with those of the Woodbine waters, the reader will see that for the most part the Glen Rose waters run higher in total solids, sodium, calcium, magnesium, chlorides, and sulphates, and lower in carbonates and bicarbonates.

Fluid temperatures.—Observations were made on the temperature of the oil and water produced from the Woodbine by certain wells in the different fields. Briefly, the records showed that at Mexia the temperatures ranged from 80° to 120° or 125°; at Wortham, from 80° to 128°; at North Currie, from 77° to 100° ± ; at Richland from 80° to 125°; and at Powell, from 80° to 120°. The lower figures represent the temperature of clean oil, as a rule with some gas. With the approach of water in the well the temperature rose. The appearance of water in the several fields was not marked by any particular temperature, but by the time a well was making more than 50 per cent water, the temperature of the fluid had generally mounted to a point between 105° and the maximum recorded.

There can be little question that the normal earth temperature for the depth of the pay sand in each of these fields is approximately equal to the maximum observed temperature of the water yielded by the wells. This would be between 122° and 128° F. for depths ranging from 2,900 to 3,000 feet. We must attribute the lower temperatures, whether of oil

TABLE XVIII

COMPARISON OF LOWER CRETACEOUS WATERS

	Location	Source of Water (in Feet)	Total Solids PPM.*	Sodium		Calcium		Magnesium		Sulphates		Chlorides		Bicarbonates	
				PPM.	Percentage RV.†	PPM.	Percentage RV.	PPM.	Percentage RV.	PPM.	Percentage RV.	PPM.	Percentage RV.	PPM.	Percentage RV.
Pandem Oil, Bassett No. 1	Southern Limestone County	4,445 Glen Rose	24,371	8,680	46.40	343	2.10	149	1.50	2,401	614	12,478	43.23	314	.63
Humphreys, Jones No. 1	Kosse area, Southern Limestone County	Below 3,770	51,462	18,564	45.45	1,064	2.99	377.5	1.56	401	.47	30,600	48.69	450	.84
E. L. Smith, Steubenrauch No. 1	Mexia field	5,732 Glen Rose	153,500	39,794	38.56	8,454	9.4	1,122	2.06	1,877	.87	78,055	49.05	228	.08
Sun Oil Co., H. A. Swink No. C1	North Currie field	4,843 Glen Rose	28,605	9,798	43.52	1,272	6.48	0	0	518	1.10	16,888	48.66	114	.19
Sun Oil Co., H. A. Swink No. C1	North Currie field	5,180–5,186 Glen Rose	49,509‡	16,454	42.03	2,105	6.17	372	1.80	1,207	1.48	29,158	48.32	213	.20
Sun Oil Co., H. A. Swink No. C1	North Currie field	5,189 Glen Rose	51,364‡	17,060	42.00	2,210	6.24	378	1.76	1,236	1.46	30,287	48.37	193	.17
Sun Oil Co., H. A. Swink No. C1	North Currie field	5,408–5,415 Glen Rose	83,820‡	25,590	38.22	5,450	9.35	860	2.43	955	.68	50,793	49.22	172	.10

* PPM. means parts per million, by weight.

† Percentage RV. means percentage reacting value.

‡ These lower waters were no doubt mixed with some water from 4,843 feet, since casing was set at 3,843 feet. Actually the lower waters would probably run higher in total solids and in all the constituents listed except carbonates and bicarbonates.

or water or of oil plus water, to the cooling effect of expanding gas which ascended with the oil and water.

SOURCE OF THE WOODBINE OIL

The problem of source.—Our object here is not to enter into an extended discussion of all the many phases of the problem of the origin and accumulation of oil, but rather to assemble for consideration those facts which seem to be most pertinent to this problem in the region of the Mexia and Tehuacana fault zones. The important question—a question of really great practical importance, although perhaps indirectly so—is, Whence came the petroleum which was discovered in the Woodbine formation in the pools of this region? Did the oil come from a source rock stratigraphically close to the pay sands? If so, did it migrate up-dip, or did it migrate down-dip, to its present containing reservoir, after traveling possibly as much as several miles; or did it come only a relatively short distance across the fault, from the downthrown Eagle Ford, perhaps, into the upthrown Woodbine? Or did this petroleum come up the faults from some comparatively deep source? Each one of these theories has its strong advocates among geologists who have given considerable thought to the matter.

Time when oil came into reservoirs.—Bear in mind that we are discussing ten distinct pools, eight of which are in one zone of faulting and two of which are in another parallel zone of faulting (Fig. 2), and all of which are on weak folds associated with major faults having a west downthrow ranging from 400 to 650 feet. On each structure the displacement brings upthrown (east) Woodbine against downthrown (west) Eagle Ford. As already explained (p. 357) there are good reasons for believing that the folding and faulting were essentially contemporaneous. This being the case, the petroleum accumulated in these ten structures *after* faulting. The writer cannot grant, as some geologists have claimed, that the oil and gas collected in these folds prior to the faulting, for the folds did not then exist. These structures in their present form served as the collecting reservoirs for the petroleum. Since the principal faulting was post-Wilcox, the accumulation must have been post-Wilcox. In the case of those faults that now show considerably greater displacement in the Cretaceous strata than in the Midway (p. 356), accumulation of oil may have commenced in post-Cretaceous, pre-Midway time.

Thickness of sedimentary prism above present surface.—It is interesting to estimate what may have been the maximum thickness of the sedimentary prism formerly overlying the region of the Mexia fault zone.

The displacement of the Wortham fault proves that there must have been at least 600 feet of strata now removed from above the upthrown block in the vicinity of the field. On the other hand there are no outliers of Tertiary formations more than a few miles up-dip from the Mexia fault zone, and there are no known reasons for assuming that these formations were ever very thick in this district. Probably a maximum thickness of not more than 1,000 or 1,500 feet of sediments was at any time above the position of the present land surface. If we assume that the Woodbine pay sand was once at a depth of 4,000 feet below the earth's surface, the temperature at that depth would have been 140° or 145° on the basis of existing conditions of temperature gradient. It may have been a few degrees hotter, due to a somewhat steeper temperature gradient in Tertiary time, when the oil began to collect in the Woodbine reservoirs.

Failure to discover Woodbine oil along faults north and south in Mexia chain of fields.—Southward, beyond the Groesbeck fields, and northward, beyond the Powell field, are other faults of the Mexia type within the Mexia zone, but, in spite of the fact that several of these have large displacements, commercial production in the Woodbine has not been found associated with them. Many dry holes have been drilled, some of them apparently well located from the standpoint of structure.

The absence of oil southward may be accounted for by the pinching out of the Woodbine sand. This formation becomes more shaly south of Mexia, and even at Nigger Creek and in the Groesbeck pools the uppermost sands of the Woodbine farther north are represented by shale.

The absence of oil northward is more difficult to explain. The writer has previously (p. 331) referred to the "speckled shale" in the basal portion of the Eagle Ford. This "speckled shale" has been found to contain ample evidence of organic remains, according to some paleontologists. Earl A. Trager,[1] after a very careful microscopic study of cores from many wells in and near the Mexia fault zone, reached the conclusion that this "speckled shale" was the most probable source of the oil in the Woodbine, and he points out that this speckled phase thins out northward, disappearing beyond Kaufman County.[2] He also found that the Eagle Ford becomes more sandy northward through Henderson and Kaufman counties. In other words, Trager, regarding the Eagle Ford as the source rock

[1] Oral communication.

[2] "Speckled shale" was reported by F. E. Heath from the Warren well drilled by Haynes and Kelsey 4 miles north of Terrell in north Kaufman County, and from the Rycade Oil Company's Holden well near Quinlan in southern Hunt County; but it was in the middle or upper part of the Eagle Ford, and was not as thick as it is farther south.

of the Woodbine oil, attributes the absence of oil on tested structures north of Powell at least in part to a lithologic condition in the shale, a condition unfavorable for the generation of petroleum.

The fact should also be remembered that in this part of the East Texas geosyncline, where at the depth at which the Woodbine is intersected by the faults (in Kaufman County, for example) this sand is coarser and more porous than farther south, and is farther from the down-dip edge where it grades into shale—that in this part of the geosyncline the flushing action of circulating ground waters may have been more effective either in preventing accumulation or in removing petroleum already accumulated in these structures. And there is still another possibility which has not yet been certainly discounted by drilling, namely, that these major faults may not be associated with structural closure adequate for accumulation.

As regards west-downthrow faults east and west of the Mexia zone, none of those so far drilled and tested within the north-and-south range of the producing fields has had more than 200 or 250 feet of throw, if we except the Nigger Creek and Cedar Creek structures. It is possible that the warping of the strata, if there was any such against these faults, was not enough to produce closure for oil accumulation.

The bearing of water analyses on the problem of the source of the oil.—Because of the close relationship of oil and water on the producing structures, some study of water analyses and water levels was made in the search for a key to the problem of oil source and oil accumulation. Until the discovery of the Nigger Creek pool there seemed to be rather definite vertical limits beyond which oil pools were not to be expected in the Woodbine sand. As may be seen by reference to Table VII on p. 353, the highest edge-water contact was observed in the Mexia field[1] (2,480 feet below sea-level), and the lowest, in the Richland field (approximately 2,620 feet below sea-level). The lower bounding edges of all the Mexia zone pools thus fell within a vertical range in depth of only 140 feet. Concerning this relation Whitehead and Fash wrote:[2]

The general conditions for accumulation of oil and water in the Powell and Mexia fields appear to be the presence of a sand body on the upthrow side of a fault at such a depth that the action of the downward migrating meteoric waters and upward migrating connate waters is arrested in what may be called a neutral zone. Munn has discussed this point in his article entitled, "The

[1] The exact figure for South Groesbeck is undetermined.

[2] R. B. Whitehead and R. H. Fash, "A Study of the Application of Oil Field Analyses to the Fault Zone Type of Accumulation" (1924), p. 4. (Not yet published.)

Anticlinal and Hydrostatic Theories of Oil and Gas Accumulation," *Econ Geol.*, Vol. 11, pp. 509–29. If a fault and sand body are found up-dip from this neutral zone, the effect of the downward migrating meteoric waters could flush out the oil unless a tremendous uplift or fault would bring about conditions which would permit an accumulation of oil. Again, a fault and sand body down-dip from this neutral zone would come under the influence of the hydrostatic head of connate waters from the east and likely would flush out the oil unless some exceptional condition of folding and faulting existed.

Since this statement was made, the Nigger Creek and Cedar Creek pools have been discovered, both of them *small* pools, although associated with large fault displacements. The east water-oil contact at Cedar Creek is about 2,385 feet below sea-level, or 125 feet higher than in the Mexia pool. Thus, the vertical range within which these Woodbine pools occur, as far as we know now, has been increased from 140 feet to 265 feet. We believe that there is a chance that pools will be found with their oil-water contact lower than 2,620 feet below sea-level, where adequate fault structures are nearer the down-dip edge of the Woodbine sand than the structures so far tested in Henderson and Kaufman counties.

As we have pointed out on page 373, Woodbine waters obtained from wells near the faults in the Mexia zone carry an abnormally high percentage of total solids. Whitehead and Fash made a strong plea for the theory that this locally high concentration was caused by admixture with relatively strongly mineralized waters ascending along the faults; and, they argued, if water can come up the faults, why not oil also? Following are quotations from their paper:[1]

Any fault may allow the upward migration along the fault plane of deep-seated waters which in turn will penetrate into the sand or porous horizons on either side of a fault plane into the zones which afford the least resistance. In fact, the writers first conceived the idea of these sources of deep-seated water from data collected from the Jones No. 1 well at Kosse. Cuttings were analyzed daily and the drilling stopped in the Georgetown series where production was apparently found. Some water was present with the oil originally. Shortly afterward, without any apparent reason, the well stopped flowing very suddenly and some weeks later upon agitation started flowing great volumes of water with oil. This second flow of water was found to be more saline than the original water found with the oil. A study of this well revealed that the original hole was drilled into the Georgetown limestone, and that the sudden stopping of the flow of oil was produced during a natural bridging below the bottom of the drill hole in the cavern or fissure through which oil and water were migrating from below with tremendous pressure, dislodging fragments of lime which were

[1] *Op. cit.*, p. 5.

carried to the surface and upon analysis were found to be Glen Rose in age, which lime series is found several hundred feet below the Georgetown lime in which the hole was terminated. This proved conclusively that the source of oil at Kosse was deep seated.

From the conclusions we quote:[1]

A deep-seated source of water and oil is known to exist at Kosse below the stratigraphic position of the Woodbine. This water may be coming from the Glen Rose series or below.

Providing the pressure of the water coming up the fault plane counterbalances the pressure of the original water found in the Woodbine sand and Georgetown limestones adjacent to the fault, any oil carried with the water up the fault plane could accumulate in this neutral pressure zone. Analyses of waters show the limits to which the fault plane water penetrated.

From the fact that most subsurface producing structures are associated with faulting, it is assumed from a study of the data submitted above that the accumulations of oil along a fault line may be due in part or in whole to migration of oil up the fault plane and out into porous zones of least resistance.

Now, the whole problem of the source of the Woodbine oil boils down to the question whether this oil migrated principally up the faults or principally along the bedding (whether up-dip, down-dip, or across the faults). This question is vital, not only as regards the Mexia zone, but also in general as affecting many oil fields in many regions. It is therefore a problem well worth consideration.

That oil, like water, may migrate along open fractures or faults, the writer does not question. But he does not believe that more than a small proportion of the oil now in the Woodbine sands, in the Mexia zone structures, had a deep-seated source. The writer believes that this oil originated in beds stratigraphically close to the Woodbine sand. These beds were most probably in the Eagle Ford shale formation, but possibly to some extent in the Woodbine formation itself, for there are plentiful organic remains in the Woodbine.

Evidences for lateral migration versus migration up the faults.—The writer's reasons for dissenting from the theory of a deep-seated source are suggested as follows.

1. All the Woodbine oils are very similar in general character, except for the variations in gravity which appear to be intimately related to local conditions pertaining to each individual pool (p. 370). For instance, the paraffin content for all the Woodbine oils from nine pools (Cedar Creek omitted) lies between 1.15 and 2.84 per cent, whereas the Glen Rose oil, in the two samples examined, contained 6.82 and 8.45 per cent.

[1] *Ibid.*, p. 12.

If the Woodbine oil came up the faults from the Glen Rose, or from a deeper source, why are not the Woodbine and Glen Rose oils more alike?

Moreover, along this same line of thought, if the Woodbine oil came up the faults, is it not probable that the oil in the Corsicana and Nacatoch sands came up the faults? There is no good reason why the faults should have served as open channels up to the Woodbine sand and then become sealed against further upward migration. If these different sands were fed by oil ascending the faults, we should expect to find some sort of progressive relationship between them, from below upward. As shown in Table IX, there is no such relationship observable. Indeed, Matson called attention to the fact that, within the producing zone in some of the shallow pools of Navarro County, a gas pay sand may lie below an oil pay sand, and he cited this as evidence against vertical migration.[1]

2. Many dry holes drilled outside of the limits of the oil pools reported showings in the Woodbine sand. In some cases the showings were so good that the wells could have been completed as very small producers. This is the opinion expressed by several disinterested persons who were at the wells when the showings were encountered. These oil showings in the upper Woodbine pay zone, discovered in widely scattered wells, suggest proximity to the source rock (probably Eagle Ford or Woodbine or both). In reply to this argument it has been said that the microscopic arrangement of the grains in the pay sands within the oil fields is very different from that of the grains in the Woodbine sands cored in the nonproducing dry holes, the former type of arrangement being indicative of lubrication by the oil; but the writer would say that original migration of oil through sands was probably never, at any one time, in quantities sufficient to affect rearrangement of the sand grains by lubrication.

3. The Mexia and Currie fields in particular have an upper zone containing several pay sands in the uppermost part of the Woodbine formation, and a lower "pay" (Kollman or Morrow) 200 to 300 feet below the upper zone. Bottom water is found in the lower sands of the upper zone. If the oil came up the faults from a deep source, why did it not accumulate in other sand members of the Woodbine? There *are* other members which, as far as their lithology goes, are essentially similar to the beds which contain the oil. This statement applies to all the fields in the Mexia zone. These other water-bearing members have shale or lime cap rocks which ought certainly to have served to retain some of the oil that was passing upward across the faulted edges of these members to the higher beds in which it accumulated.

[1] G. C. Matson and O. B. Hopkins, "The Corsicana Oil and Gas Field, Texas," *U. S. Geol. Survey Bull. 661* (1917), p. 241.

If it be argued that these sands perhaps did contain some oil, but that this oil was flushed out, the reply is that such flushing must then have come from the east—not up the fault nor from the west across the fault—because waters from these lower Woodbine sands are less concentrated than waters taken from the upper Woodbine sands in the same wells, and are of the same character as the upper Woodbine sand waters east of, and not closely associated with, the faults. If such supposed "flushing" water had come up the dip from the east with a sufficiently strong head to remove the oil or to prevent the accumulation of the oil in its aquifer, it would have passed on up the faults (assuming them to have been open channels according to the theory of upward migration) and at least it would have lowered the concentration of the upper Woodbine waters which are now closely associated with the faults. Or, on the other hand, if the "flushing" waters had come up the faults, it would have caused much higher concentration of solvents in these oil-free Woodbine sands.

Indeed, why are not these "fault waters" much more concentrated than we find them, if they came up from deep sources where we find waters running from 50,000 to 150,000 parts per million total solids (Tables XIII, XVIII)? And bear in mind that we must predicate, as a working hypothesis, either that all these waters which we are discussing had essentially the same characters that we now observe in them, during the period of oil accumulation, *or* that probably *none* of them had these present characters during that period. In other words, unless we are willing to admit that there has been comparatively little modification of these waters since the time when the oil was in process of accumulation, we cannot use their composition variations to assist us in the solution of the problems of oil migration and accumulation.

4. Additional evidence against much migration of water (and therefore of oil) up the faults is borne out in the higher concentration of waters in the Nacatoch and Corsicana sands than in the Woodbine sand within the Powell field proper. Here Sutton reports that waters from the downthrown Nacatoch sand averaged 20,100 parts per million total solids, waters from the upthrown Corsicana sand averaged 20,450 parts per million, and water from the downthrown Corsicana sand, close to the fault, contained 34,750 parts per million of total solids in solution. Yet the Woodbine waters contained between 8,000 and 19,000 parts per million.

5. In other areas where oil is produced, students of the problem of oil accumulation believe that the oil came from beds stratigraphically very near its containing reservoir rock. Thus, P. W. McFarland,[1] writing of the

[1] Pp. 389–408.

Laredo pools, came to the conclusion that the faults here, although important in their relations to the structural conditions, did not function as channels for the accumulating oil.

The writer has long felt that no better example could be offered of lateral migration as against transverse migration along faults than the pools of southern Archer County and northern Young County, Texas. It was for this reason he urged the description of this region.[1] Here there are forty or more separate pools, all of which produce from the *same* sandy zone which is only 50 or 60 feet thick, and all of which yield the same kind of oil. Yet these pools produce from depths of less than 500 feet to depths of fully 1,500 feet in different parts of the regional dip. Within this area, containing these forty or more pools, several sands have been encountered within 300 or 400 feet above and below the main "pay," but none of these has carried oil. Surely this must mean that the oil in all these pools originated from the *same* source and that this source rock must be relatively few feet from the pay sand into which the oil came and along which it traveled principally by lateral migration.

And if the oil accumulated by lateral migration in Archer and Young counties, why not by lateral migration in the Mexia zone, where many evidences point to the same conclusion?

As for the theory that the oil came across the fault from the adjacent Eagle Ford, the writer admits that some oil might enter the upthrown Woodbine in this manner, but he cannot admit that the fortuitous relation of downthrown Eagle Ford against upthrown Woodbine is the main reason for the occurrence of these particular accumulations of petroleum in the fault zone. Under no circumstances is there a sufficient body of Eagle Ford shale brought down against the Woodbine sand to account for the volume of oil in the associated pool, unless by reason of extensive migration down the dip and along the strike. We are therefore led back to the necessity for lateral migration.

6. Drilling and plugging operations have demonstrated that there are local open channels in the fault zone, but these are rare. Not only did the behavior of the wells in most cases indicate nothing more than the ordinary connection through the pores of the sands, but also common experience in faulted districts would lead a geologist to infer that these faults must, for the most part, be sealed because of the bodies of rather soft shale present in the Lower Cretaceous and especially in the Upper Cretaceous (see "Stratigraphy").

[1] W. E. Hubbard and W. C. Thompson, "Geology and Oil Fields of Archer County, Texas," *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), pp. 457–81.

Conclusion.—Summarizing, the data available on the oil and gas pools of the Mexia and Tehuacana fault zones seem to point to these conclusions:

1. That the origin of the reservoir structures, and therefore accumulation of the petroleum in these structures, was post-Cretaceous and to a considerable extent post-Wilcox in age.

2. That the source of this petroleum, now in the Woodbine sand, was probably in the Eagle Ford shale and in the Woodbine formation itself.

3. That this petroleum migrated into its containing reservoir structures principally by movement along the bedding, and to only a slight extent across the bedding.

4. That the faults did not function, except to a very slight extent and only locally, as avenues of upward migration of petroleum.

Whether lateral migration was mainly down-dip or up-dip to the reservoirs in the Mexia zone the writer is not prepared to discuss. In differing degrees it may have been in both these directions, and along the strike, depending on local conditions such as dip, depth, porosity, and stratigraphy. That oil migration and accumulation have very definite relations to conditions of water circulation, the writer feels convinced; therefore, he urges that, whenever feasible, thorough and comprehensive investigations be undertaken to analyze and compare the waters associated with oil fields, especially for some distance out from the fields in all directions.

One of the strongest evidences against the theory of a deep source for the Woodbine oil, or for the other oils associated with the fault structures, is the absence of any observed gradational relationship between these oils, or between the waters in the sands on these structures, from below upward through the formations.

The argument frequently offered by adherents of the vertical- or fault-migration theory—that if the oil came from the shale stratigraphically near the reservoir sand, there is not sufficient shale to have produced so much oil unless the oil traveled long distances to its present containing structure, and since such extensive migration is unbelievable, therefore the lateral migration theory is improbable—this argument carries no weight, since not enough is yet known about the mode of origin and manner of circulation of oil within the interstices of rocks. Referring again to southern Archer County, the lenticular, discontinuous character of the oil-bearing sand in that district suggests that the accumulation of considerable bodies of oil may be explained without invoking migration for long distances.

LAREDO DISTRICT, TEXAS[1]

P. W. McFARLAND[2]
San Antonio, Texas

ABSTRACT

The Laredo district is in the extreme southern part of Texas and includes five counties: Duval, Jim Hogg, Webb, Starr, and Zapata.

Oil and gas production is obtained from the Fayette, Yegua, and Cook Mountain formations of Eocene age. In general, oil production has been rather disappointing, due to irregular sand conditions, but the presence of commercial quantities of oil at shallow depths in such a large area indicates the possibilities of better production when the proper combination of sand and structural conditions are encountered.

Faulting and sand lensing are the principal factors of the accumulation of oil and gas in this district. Although the major part of the folding and faulting is post-Eocene in age, some movement took place throughout Eocene time. This movement appears to have controlled the position of shore lines at intervals during the Fayette period.

INTRODUCTION

In preparing this paper the writer is indebted to F. H. Lahee and Charles H. Row for helpful criticisms and suggestions, and to Joseph M. Wilson, of Dallas, Texas, for subsurface data on the Randado field and the location of the Reynosa escarpment in Jim Hogg and Starr counties.

Oil and gas in commercial quantities were discovered in April, 1921, and development has gradually spread until producing fields have been found in an area approximately 50 miles long and 20 miles wide. These fields are all closely connected geographically. The major part of the oil and gas production has been from a depth of less than 2,000 feet.

The producing fields in the Laredo district are Aviator-Schott, Carolina-Texas, Cole, Charco-Redondo, Jennings, Henne-Winch-Fariss, Mirando Valley, and Randado. The Jennings field has produced only gas. The Carolina-Texas and Cole fields are primarily gas fields and have produced only small amounts of oil. The remainder of the fields mentioned are oil producers. Structurally, the Schott and Aviator fields may be considered as one field.

[1] Presented by title before the Association at the Tulsa meeting, March 26, 1927. Manuscript received by the editor, October 20, 1927. Published with permission of F. H. Lahee, chief geologist of the Sun Oil Company.

[2] The Sun Oil Company.

HISTORY OF DEVELOPMENT

The oil production of each field from the date of discovery until June 30, 1927, is shown in Table I.

TABLE I

Production of Laredo District

Field	Number of Wells (June 30, 1927)	Daily Average (Barrels)	Total Production (Barrels)
Aviator	154	2,345	2,646,823
Carolina-Texas	3	28	22,267
Cole	6	....	161,975
Charco-Redondo	66	46	8,650
Mirando Valley	15	74	473,075
Randado	132	2,827	1,439,650
Schott	193	1,725	5,956,821
Henne-Winch-Fariss	101	1,278	2,666,110
Total of all fields	670	8,323	13,375,371

Altogether, 1,775 tests have been drilled in this district. The peak of production was reached in August, 1926, with a daily average of 16,291 barrels. At present, gas production has become an important factor in this area. Three gas lines are taking gas from wells in the Carolina-Texas, Cole, and Jennings fields, and another line is under construction to these fields. The Southern Natural Gas Company has a 12-inch line to San Antonio; the Houston Oil Company has a 12-inch line to Houston; and the Border Gas Company, a 6-inch line to Laredo. Other interests are constructing a 6-inch line to the Rio Grande valley and Brownsville.

On June 30, 1927, these lines were taking approximately 40,000,000 cubic feet of gas per day. Of the total amount, the Houston Oil Company was taking 34,000,000 cubic feet per day through its line to Houston. In all, 165 gas wells are available, although less than half of these are now being drawn on.

STRATIGRAPHY

Very little paleontological information has been obtained on formations above the producing horizons, and the exact thickness of the different formations has never been worked out. Thicknesses measured at the outcrops are not very reliable on account of poor exposures and gentle dips. It is certain that the thickness of each formation is greater in the producing area than in the sections measured at the outcrop by Trowbridge[1] and Deussen.[2] It is possible, however, that this greater thickness

[1] A. C. Trowbridge, "A Geologic Reconnaissance in the Gulf Coastal Plains of Texas Near the Rio Grande," *U. S. Geol. Survey Prof. Paper 131-D*, 1924.

[2] Alexander Deussen, "Geology of Coastal Plains of Texas West of the Brazos River," *U. S. Geol. Survey Prof. Paper 126*, 1923.

may be accounted for by the general thickening of the formations eastward toward the Gulf coast. The classification in Table II shows the formations drilled through and the approximate thickness of each.

TABLE II

FORMATIONS IN LAREDO DISTRICT

			Approximate Thickness in Feet
Pleistocene	Reynosa		175
Miocene	Oakville		200
Miocene or Oligocene	Gueydan		850
Eocene	Frio	Jackson	200
	Fayette	Jackson	850
	Yegua	Claiborne	700
	Cook Mountain	Claiborne	1,000
	Mount Selman	Claiborne	700
	Carrizo	Wilcox	80

Reynosa gravels.—The Reynosa in this area consists of 150–200 feet of caliche, coarse sands, gravels, and layers of hard siliceous cemented sandstone. It lies unconformably on all the older formations and shows much less dip than the underlying strata. The lack of consolidation of the greater part of the formation, together with the unconformity at its base, precludes any possibility of mapping surface structure in areas covered by it.

Oakville sandstone.—This formation is composed of coarse conglomeratic sands, in places hardened by siliceous cement. The average thickness is 200 feet.

Gueydan formation.—The Gueydan, according to Bailey,[1] consists of 850 feet of volcanic conglomerates, sandstones, and tuffs. The material of the Gueydan appears to have been derived from near-by volcanoes.

Frio clays and shales.—The Frio consists of approximately 200 feet of gray, blue, and red shales and clays with a few layers of sand and sandy shale. Several beds of volcanic material are also found throughout this formation.

Fayette.—The Fayette consists of 700–1,000 feet of sand, sandy shale, and volcanic material. Sandy material is predominant throughout the

[1] Thomas H. Bailey, "The Gueydan, A New Middle Tertiary Formation from the Southwestern Coastal Plains of Texas," *Univ. of Texas Bull. 2645*, 1926.

formation. The greater part of the oil and gas production of this district is obtained from Fayette sands.

Yegua.—The contact between the Fayette and the Yegua has never been determined satisfactorily from well logs and cuttings, but it is probable that the thickness of the Yegua does not exceed 700 feet. The Yegua is predominantly shale and gumbo with a few lenticular sands.

Cook Mountain.—This consists of at least 1,000 feet of micaceous sands, sandy shales, and shales. The individual sand layers are ordinarily thin and well bedded. Considerable amounts of black shales are found in the Cook Mountain.

Mount Selman.—The Mount Selman is composed of brown and blue sands and shales with much iron ore and lignitic material. Its thickness ranges from 600 to 800 feet.

Carrizo sandstone.—This is a soft brown sandstone 60–100 feet in thickness. Where encountered at shallow depths this sand generally carries artesian water.

PRODUCING HORIZONS

Commercial oil and gas have been found in five sand horizons throughout the area, as shown in Table III.

TABLE III

OIL AND GAS SANDS

Fayette	Cole sand Mirando sand
Yegua	Schott sand
Cook Mountain	Webster sand Carolina-Texas sand

Cole sand.—The Cole sand which is in the upper part of the Fayette is a prolific producer of gas in the Cole field and a good oil producer in the Randado field. Its average thickness is 25 feet, with irregular shale breaks. The sand is composed of quartz grains with much fine shaly material. The Cole sand is not present west of a line from the Cole field to the Randado field. It seems to represent an old shore line. In fact, sand lensing is the primary factor in accumulation in both the Cole and Randado fields.

Mirando sand.—The Mirando sand, which is the producing sand of the Schott field, has been found productive throughout a larger area than any other sand in the entire district. It is correlated with the oil-producing sands of the Schott, Aviator, Henne-Winch-Fariss, the 2,000-foot gas sand of the Carolina-Texas, and the 2,300-foot gas sand of the Cole field.

The Mirando sand consists of a horizon of sand, sandy shale, and lignite approximately 50 feet in thickness. The formation is not productive throughout its entire thickness but accumulation occurs in the most porous strata, which are, as a rule, limited to 10–20 feet in thickness. The nature of the sand and the presence of large amounts of lignite indicate deposition in comparatively shallow water. East of the line of folding mentioned later in this report in connection with the Reynosa escarpment this horizon thickens considerably, but at the west is very thin and is present only locally.

Schott sand.—This sand has been found productive only in a small area in the Schott field. It lies about 300 feet below the Mirando sand, and cannot be correlated between the different fields, as it occurs only in local lenses. The gravity of the oil obtained from this sand is 42° Bé. and very high in gasoline content.

Webster sand.—This sand lies 500 feet below the Mirando sand and is considered as the approximate top of the Cook Mountain formation. It consists of 30 feet of sand with shale partings, and rarely contains true sand of any great thickness. The sand layers consist of coarse quartz grains with very few shale impurities. This horizon produces gas and high-gravity oil in the Carolina-Texas field, and gas in the Jennings field.

Carolina-Texas sand.—This sand belongs to the lower part of the upper Cook Mountain and has been found productive only in the Carolina-Texas field. It consists of thin layers of sand and shale whose total thickness is about 30 feet. Good showings of 42° Bé. gravity oil have been found in this sand, but as yet it has not proved to be a commercial oil producer. Gas wells in this sand have an initial production of 10,000,000–50,000,000 cubic feet, with a rock pressure of 960 pounds.

SURFACE STRUCTURE

The outcrops of the formations in this district are of very little assistance in determining structure. The Reynosa formation lies unconformably on all the other formations in the area. The Reynosa escarpment, which is the most prominent topographic feature of the region, can be traced for approximately 150 miles from Rio Grande City through Starr, Jim Hogg, Zapata, Webb, Duval, and McMullen counties (Fig. 1). In some places it has a relief of more than 100 feet.

All the oil and gas fields of this district, with the exception of the Cole and Jennings fields, are located near the edge of this escarpment. In the past the theory of a fault scarp has been advanced by some to explain its origin. Very little evidence of faulting has been found at the surface,

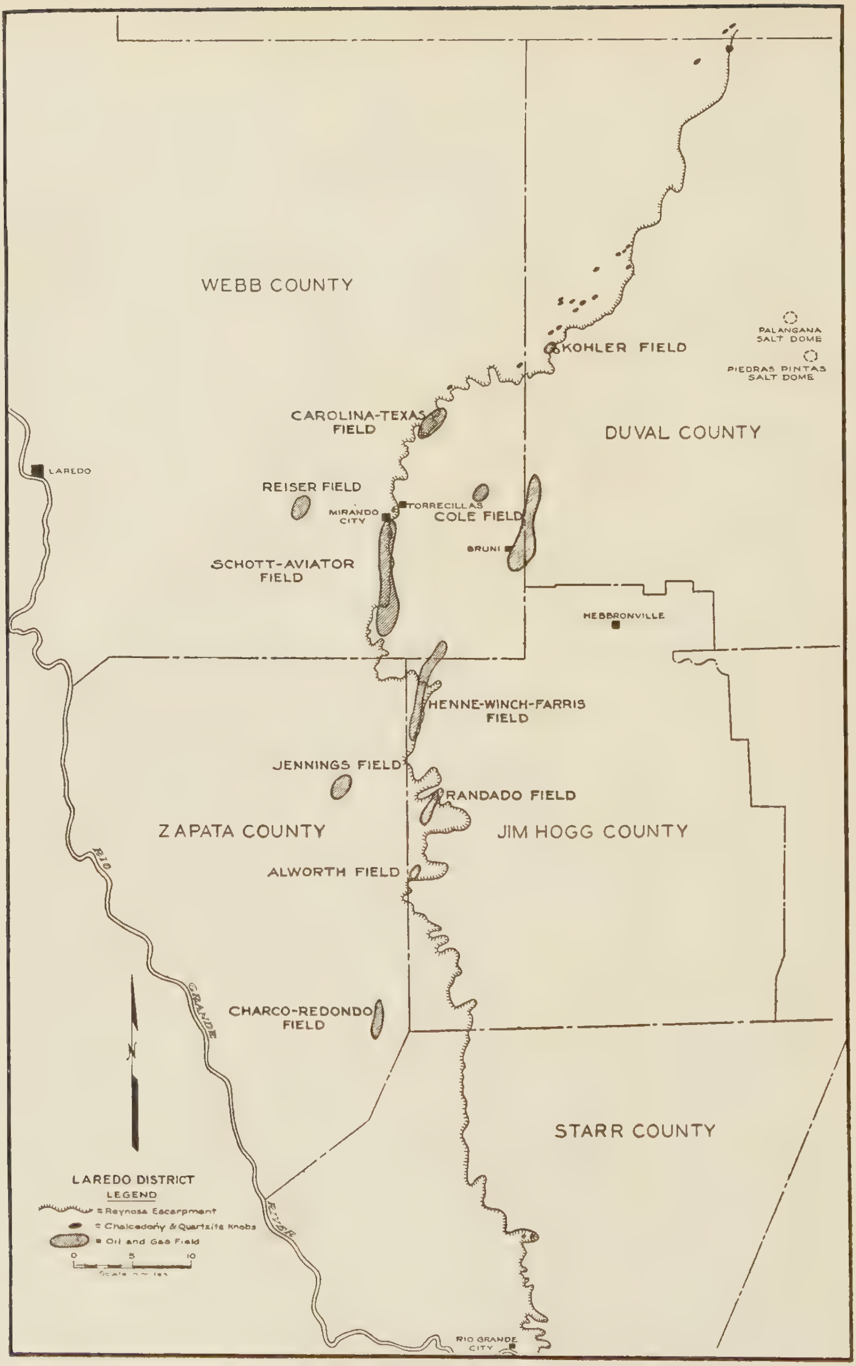


FIG. 1.—Map of the Laredo district, Texas, showing the location of the Reynosa escarpment and the oil and gas fields.

although, of course, the gravels and sands of the Reynosa and the soft tuffs and clays of the Gueydan are not the type of beds that would be expected to reflect evidence of movement.

It is the theory of the writer that the escarpment is due mainly to erosional conditions, but is also indirectly related to faulting, inasmuch as a zone of faulting may have controlled the deposition of the Reynosa in that particular area. The character of the Reynosa indicates stream deposition. A larger amount of siliceous material is found along the escarpment than elsewhere, and this may indicate an accumulation by rivers from the volcanic beds of the Gueydan which was carried in suspension and ultimately deposited along with the other sediments. Under these conditions the harder, more siliceous beds would be expected westward in the Reynosa or near the outcrop of the Gueydan, and a smaller amount eastward. The small patches of Reynosa capping the hills west of the Gueydan show very little siliceous material. It is further suggested that subsequent erosion carried away the softer phase of the Reynosa, leaving the present alignment of the escapment with its hard siliceous members. It is worthy of note that points along the escarpment show the highest elevation topographically in the district.

While erosion is probably the most important factor in the formation of the Reynosa escarpment, a general zone of faulting is closely connected with its present position. Since considerable movement had undoubtedly taken place before Reynosa time, this fault zone may have had a strong influence on the deposition of the Reynosa sediments in this area.

One of the most interesting features of the surface geology of this district is the occurrence of many veins of calcite, silicified shale, and veins and plugs of chalcedony. These phenomena are closely connected with the present position of the escarpment and are ordinarily found in a zone several miles in width bordering it on the west. In general they are found along the entire length of the escarpment from Starr to McMullen counties, with the best and most numerous exposures in northern Duval County. While none of these can be traced for more than a few hundred feet, they all have the same general strike, which ranges from due north to N. 30° E. Most of these veins and plugs are in the Oakville and Gueydan formations, although a few cut the Reynosa.

The origin of these veins and plugs is attributed to circulating waters coming to the surface along fractures and depositing siliceous material at or near the surface. As previously noted, the Gueydan and Frio formations, which underlie the Reynosa, contain beds of volcanic material, and it is probable that the siliceous material derived from these beds was

carried upward by circulating waters and deposited as chalcedony or silicified shale. Analysis of material from a vein in Survey No. 731, Duval County, shows a non-calcareous clay that seems to be an altered volcanic ash. Considerable calcite is also found in the same vein. Very little information is available regarding the depth to which these deposits extend, but it is probable that they will not be found at any great depth, since the siliceous material is most likely to be deposited near the surface.

While very few indications of displacement are found at the surface in connection with these veins, the nature of the soft sands and clays of the Reynosa, Oakville, and Gueydan formations in which they are found would tend to conceal such evidence. Also the known subsurface faults in this area show comparatively small displacement, and it is likely that the higher formations would show even less, since some movement seems to have taken place throughout the Eocene. The fact that these veins all align with the same general strike, and the fact that some check with subsurface faults, indicate a general zone of faulting and fracturing.

SUBSURFACE STRUCTURE

Faulting and sand lensing are the principal factors in the accumulation of oil and gas in this district. Two lines of faulting approximately parallel to each other are indicated by correlation of well logs. The first one of these is the controlling feature of the Aviator, Schott, and Carolina-Texas fields. The second controls accumulation in the Henne-Winch-Fariss field and appears to be a part of the same line controlling the Mirando sand production of the Cole field, although our present information does not justify extending the fault between these fields.

Accumulation of oil and gas along these faults is found under the following conditions: (1) the fault cutting a transverse fold, and (2) a change in direction of the fault. In each condition, closure against the fault affords a suitable reservoir.

In the Henne-Winch-Fariss field the faulting is of the normal type, with the downthrown block on the west. The Carolina-Texas fault, however, is of the normal type downthrown toward the east. Sand lensing is responsible for the accumulation in the Randado field and in the Cole sand of the Cole field. This sand lensing appears to represent an old shore line, and the Cole sand is not found anywhere west of these fields.

The normal dip in the producing area is approximately 90 feet per mile due east, except in northern Duval County, where it changes to S. 70° E.

CAROLINA-TEXAS FIELD

The Carolina-Texas field is located in southeastern Webb County about 8 miles north of Mirando City. It lies at the edge of the Reynosa escarpment.

Gas was discovered in this field March 18, 1922, when the Carolina-Texas Oil and Gas Trust completed their Barnsley No. 1, Survey No. 268, producing 15,000,000 cubic feet from a depth of 1,270-1,295 feet. This well made considerable water and was later deepened to 1,995–2,060 feet (Mirando sand), where it produced 25,000,000 cubic feet. In November, 1923, Barnsley No. 5, Survey No. 268, was completed by the same company, producing 65,000,000 cubic feet at a depth of 2,947–3,005 feet (Carolina-Texas sand). In October, 1925, Johnson-De Tray completed their No. 1 De la Garza, Survey 335, making 40,000,000 cubic feet at a depth of 2,525–2,530 feet (Webster sand).

In June, 1926, the Associated Oil Company brought in the first oil well of the field in their No. 2-A Webster, Survey No. 684, flowing 800 barrels of 33° gravity oil at a depth of 2,599–2,609 feet. Production in this well fell off rapidly, and at present it is pumping only a few barrels of oil per day. Subsequently tests were drilled on all sides of this producer, all of which resulted in failures with the exception of the direct offset on the west, which made 30,000,000 cubic feet of dry gas.

In January, 1927, the Magnolia Petroleum Company's Webster No. 1, Survey No. 684, was completed as a 5-barrel pumper of 45°-gravity oil at a depth of 3,042–3,049 feet (Carolina-Texas sand). Although this well has not proved to be a commercial producer, it indicates the presence of high-gravity oil in the 3,000-foot level.

In general the logs of wells drilled in the Laredo district lack definite markers for accurate correlation, especially in the section above the Mirando sand. In the Carolina-Texas field, several wells have been drilled deep enough to penetrate the Mirando, Webster, and Carolina-Texas sands, and the logs of these wells give definite indications of structure.

Structurally, this field is an anticlinal fold cut off on the west by a normal fault. This fault has a displacement of approximately 200 feet and is downthrown toward the southeast. Conditions indicate that this fault is the controlling feature of the structure and that the west or reverse dip shown in Figure 2 is due mainly to an adjustment of the strata eastward, coincident with the slipping of the downthrown block. The fault plane dips approximately 45° SE.

In Figure 3, logs Nos. 1 and 2 show the Mirando sand on the down-

thrown side of the fault and the Webster sand on the upthrown side. Log No. 2 also shows the Carolina-Texas sand on the upthrown side. Log No. 3 shows both the Mirando and Webster sands, with normal interval

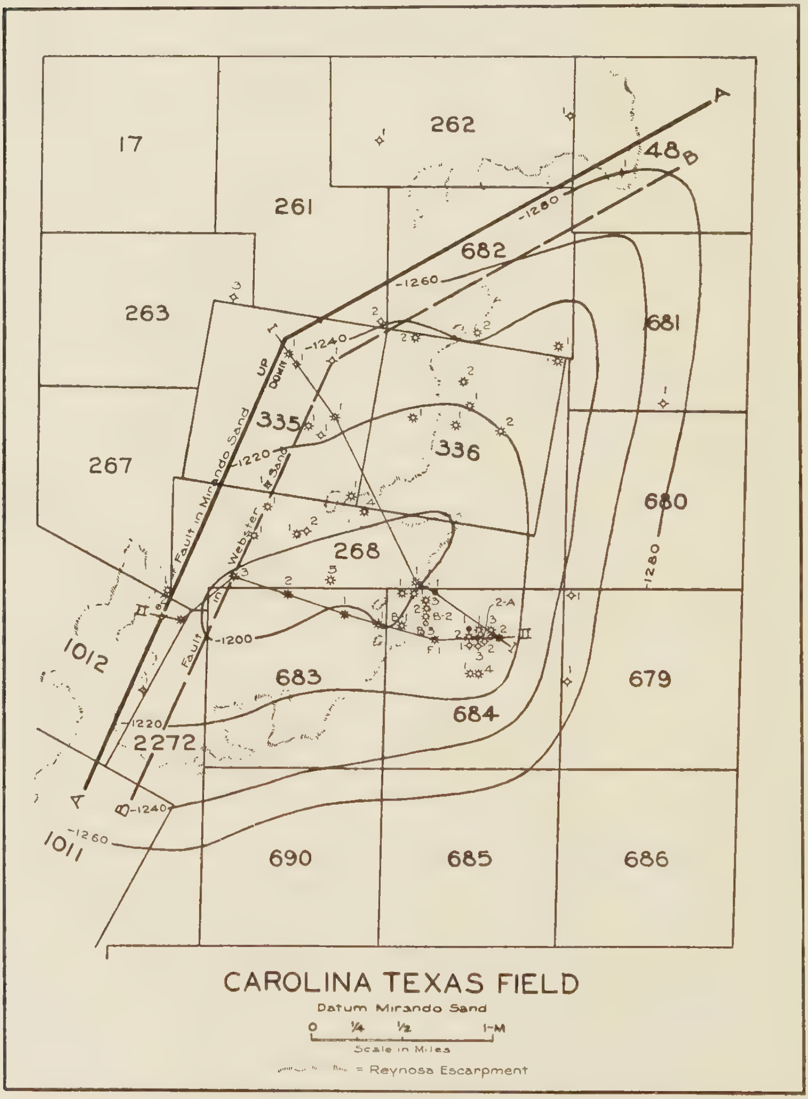


FIG. 2.—Map of the Carolina-Texas field, Webb County, Texas, showing fault in the Mirando sand and in the Webster sand. Datum, Mirando sand.

on the downthrown side. Logs Nos. 4 and 5 show the Mirando, Webster, and the Carolina-Texas sands in normal sequence.

In Figure 4, log No. 2 shows a marked decrease in interval between the Mirando and the Carolina-Texas sands with the Webster sand absent. Log No. 3 does not show the Webster sand, probably due to inaccurate

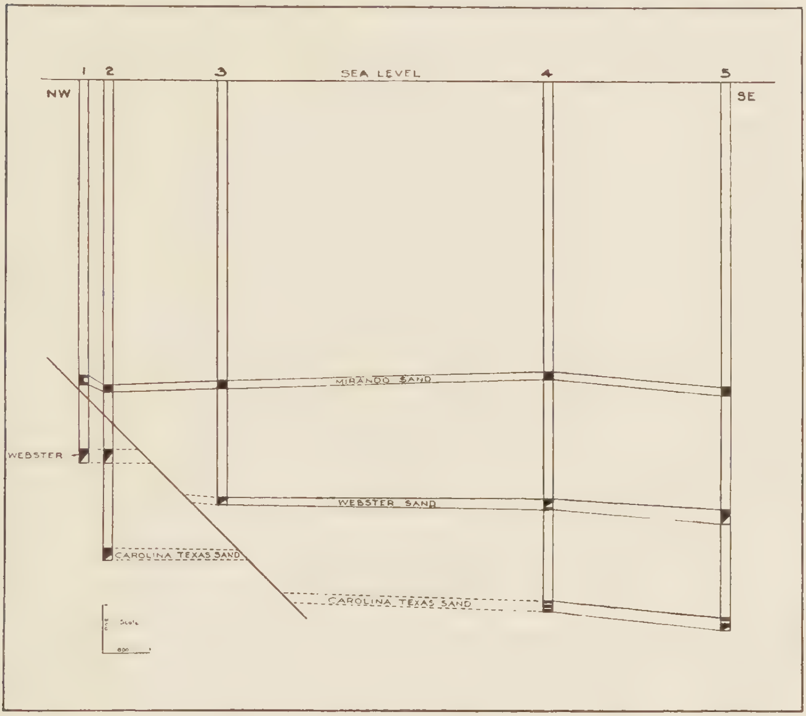


FIG. 3.—Cross section I of Carolina-Texas field. Log No. 1, Morgan Gibble's De la Garza No. 1, Survey 335. No. 2, Simmons' De la Garza No. 1, Survey 335. No. 3, Johnson-Detray's De la Garza No. 1, Survey 335. No. 4, Houston Oil Co.'s Barnsley No. 1, Survey 268. No. 5, Texas Co.'s Webster No. 2, Survey 684. Scale in feet.

logging, although in this log the interval between the Mirando and the Carolina-Texas sands is regular. Log No. 1 shows the Mirando sand 80 feet higher than log No. 2, which is interpreted as due to its proximity to the fault plane and the consequent drag of the downthrown block.

THE COLE FIELD

The Cole field (Fig. 5) is located on the Webb-Duval county lines, just east of the town of Bruni. The discovery well in the Cole field, the

Cole Petroleum No. 4, was completed July 20, 1924, at a depth of 1,700–1,705 feet as a gasser of 69,000,000 cubic feet. Subsequent development has extended the field until the producing gas area is approximately 8 miles long and from 1 to 3 miles wide. Production in this field is obtained from two sand horizons, the Cole sand and the Mirando sand.

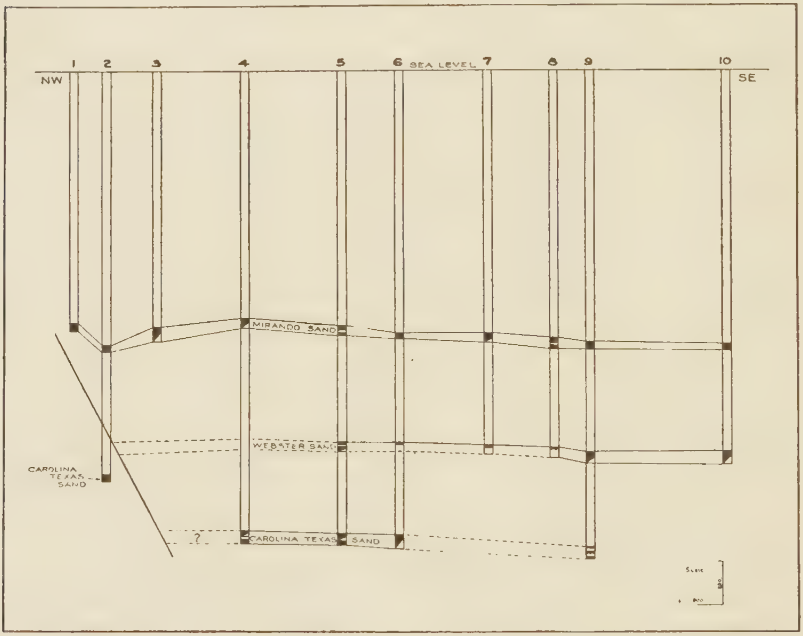


FIG. 4.—Cross section II of Carolina-Texas field. Log No. 1, Lowery's "Vela" No. 1, Survey 1012. Log No. 2, Johnson-Detray's "Vela" No. 1, Survey 1012. No. 3, Carolina-Texas' Barnsley No. 3, Survey 268. No. 4, Houston Oil Co.'s S. Benavides No. 2, Survey 683. No. 5, Carolina-Texas' S. Benavides No. 1, Survey 683. No. 6, Houston Oil Co.'s S. Benavides No. 1, Survey 683. No. 7, Associated Oil Co.'s Webster No. F-1, Survey 684. No. 8, Associated Oil Co.'s Webster No. 2-A, Survey 684. No. 9, Texas Co.'s Webster No. 2, Survey 684. No. 10, U. S. Gas & Oil Co.'s S. Benavides No. 1, Survey 679. Scale in feet.

The Cole sand, which is encountered at an average depth of 1,700 feet in this field, is a prolific gas producer and is producing more than half of the total gas production of the district. Eighty-four gas wells have been completed in this sand with initial productions ranging from 20,000,000 to 60,000,000 cubic feet each. On June 30, 1927, 19,000,000 feet per day was being drawn from forty-three of these wells.

Oil production has been rather disappointing in this field. Six oil

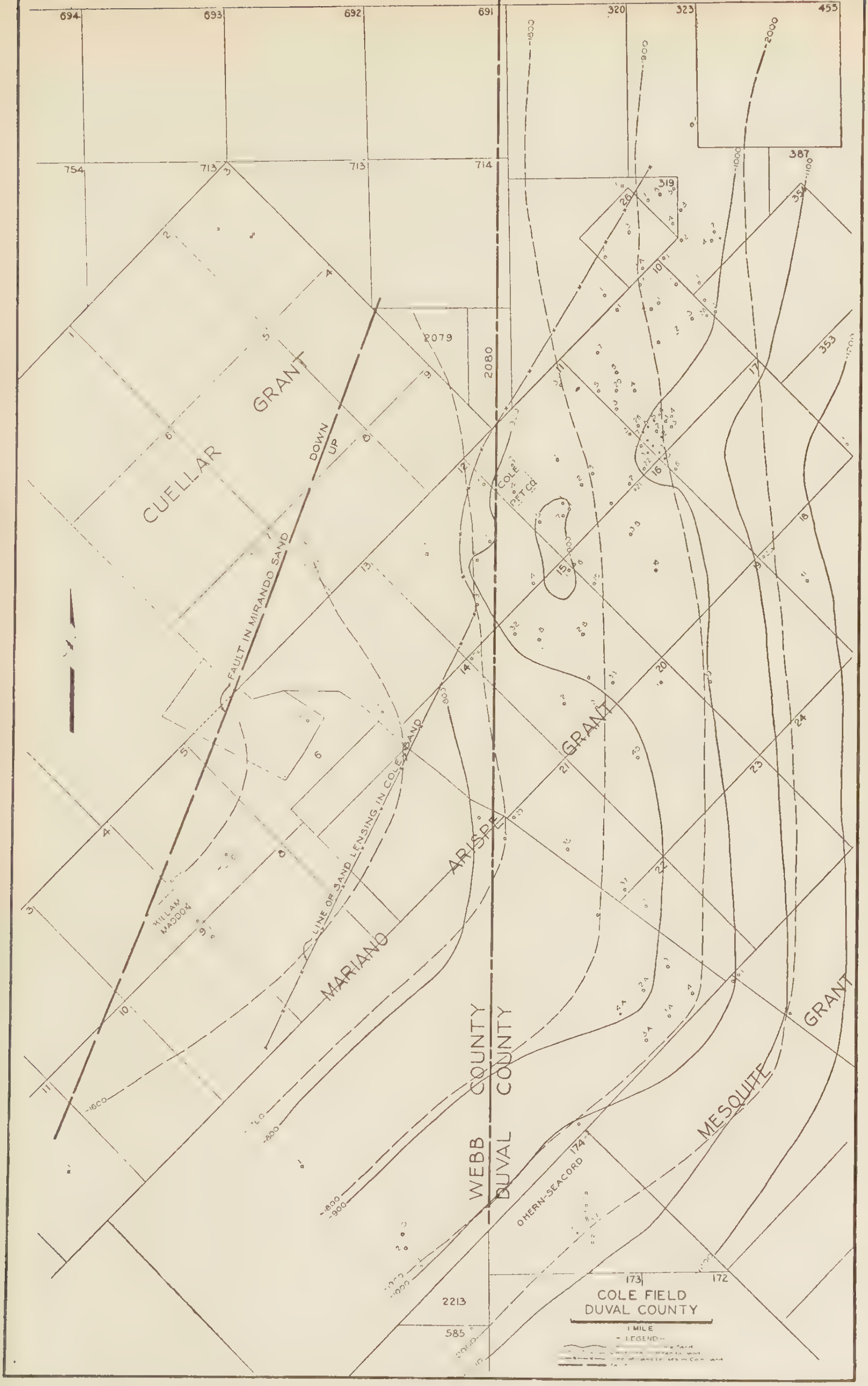


FIG. 5.—Map of Cole field, Duval County, Texas, showing fault and line of sand lenses in the Cole sand. Contours on the Mirando sand and the Cole sand.

wells were completed in Surveys 10, 11, and 17, Mariano Arispe Grant. Most of these wells were large gassers spraying oil, and have all been closed to prevent waste of gas. O'Hern and Seacord No. 5, Survey No. 174, made a small well, but offset tests were either gas wells or dry holes. On June 30, 1927, a total amount of 161,975 barrels of oil had been produced from this field, all of which was from the Cole sand.

The accumulation of gas in the Cole sand is caused by a combination of sand lensing and folding. The sand lenses out in a distinct line with a trend of N. 20° E. and is not found anywhere west of this line. Accumulation is found along this line of lensing only where it crosses a broad transverse fold that has a northwest-southeast axis, thus affording closure against the lens. The sand is much thicker on the flanks and off the fold than on the top, indicating the possibility of some of the folding having taken place at a time prior to the deposition of the Cole sand. The lensing in the Cole sand probably represents an old shore line more or less dependent on the line of faulting farther westward, as suggested elsewhere in this paper.

Sand conditions throughout the field are fairly regular, with a general thickening eastward. The productive area in this field is much wider than in any of the other fields of the district.

Gas was recently discovered in the Mirando sand in this field at a depth of 2,317 feet in the Killam-Maddox Bruni No. 1, Block 5, Survey 4, Mariano Arispe Grant. The extent of production in this sand has not yet been determined, although several dry holes throughout the field indicate that the productive area will not coincide with that of the Cole sand. Some evidence of a faulted nose is suggested in correlating the logs of wells drilled to the Mirando sand in this vicinity, but sufficient information is not available at present to be certain of this.

The average rock pressure of wells when first completed is 500 pounds in the Cole sand and 700 pounds in the Mirando sand. On June 30, 1927, the average rock pressure of all the wells in the Cole sand was 475 pounds, showing very little decrease, as some of the wells have been drawn on for more than a year. The Cole sand shows very little water in the productive area.

HENNE-WINCH-FARISS FIELD

The Henne-Winch-Fariss field is in the northwest corner of Jim Hogg County, just east of the Zapata–Jim Hogg county line. The oil and gas production at present covers an area 2,500 feet wide and 8 miles long.

The first well leading to the discovery of this field was the Henne-Winch-Fariss (now Big Bend) Martinez No. 1, Block 3, Survey 256,

which was completed making 30,000,000 cubic feet of dry gas. The same company's Martinez No. 3, Block 3, Survey 256, was completed October 30, 1924, making 1,700 barrels of oil per day. This well was located in what has since proved to be the center of the field, and a gradual extension has been made both south and north. The field has not yet been defined in either direction. Recently the Killam-Maddox Bruni No. 1, Block 65, Albercas Grant, was completed with a production of 25,000,000 cubic feet of dry gas, making a 3-mile extension toward the north.

The Mirando sand is the producing horizon in this field and is encountered at approximately 2,100 feet. Local sand lensing affects production to a small extent, but in general sand conditions are regular. On the accompanying map (Fig. 6) the contours are based on the top of the Mirando sand.

Correlation of well logs of Killam-Lang Martinez No. 1, Survey 69, and the Boston Mirando Martinez No. 1, Survey 69, shows a normal fault of 60 feet displacement. The Killam-Lang test is on the downthrown block which is to the west. No other tests have been drilled near this fault, so that we have no definite information as to its location in the northern part of the field. This fault has a due north strike and parallels the Reynosa escarpment in the southern part of the field. About the center of the field it appears to swing N. 20° E. and cross the escarpment. In the northern part of the field there is no apparent relationship between the fault and the escarpment. The change in direction of the fault affords closure in the north end of the field, where the strike of the formation is slightly east of north.

The dip of the producing sand in this field and for several miles toward the east is about 150 feet per mile, in contrast to the normal dip for the district, which is 90 feet per mile.

The initial gauges on the gas wells show an average of 25,000,000 cubic feet of dry gas. The average initial production of the oil wells when placed on the pump is 75 barrels per day. The oil wells show little gas pressure, and very few are completed as flowing wells.

RANDADO FIELD

The Randado field is in Jim Hogg County, 3 miles west of the town of Randado. This field was discovered September 25, 1925.

Figure 7 is contoured on the top of the Cole sand, which is found at 1,300 feet. Several tests have been drilled to the Mirando sand, but no production has ever been found below the Cole sand. The gravity of the oil is 21° Bé.

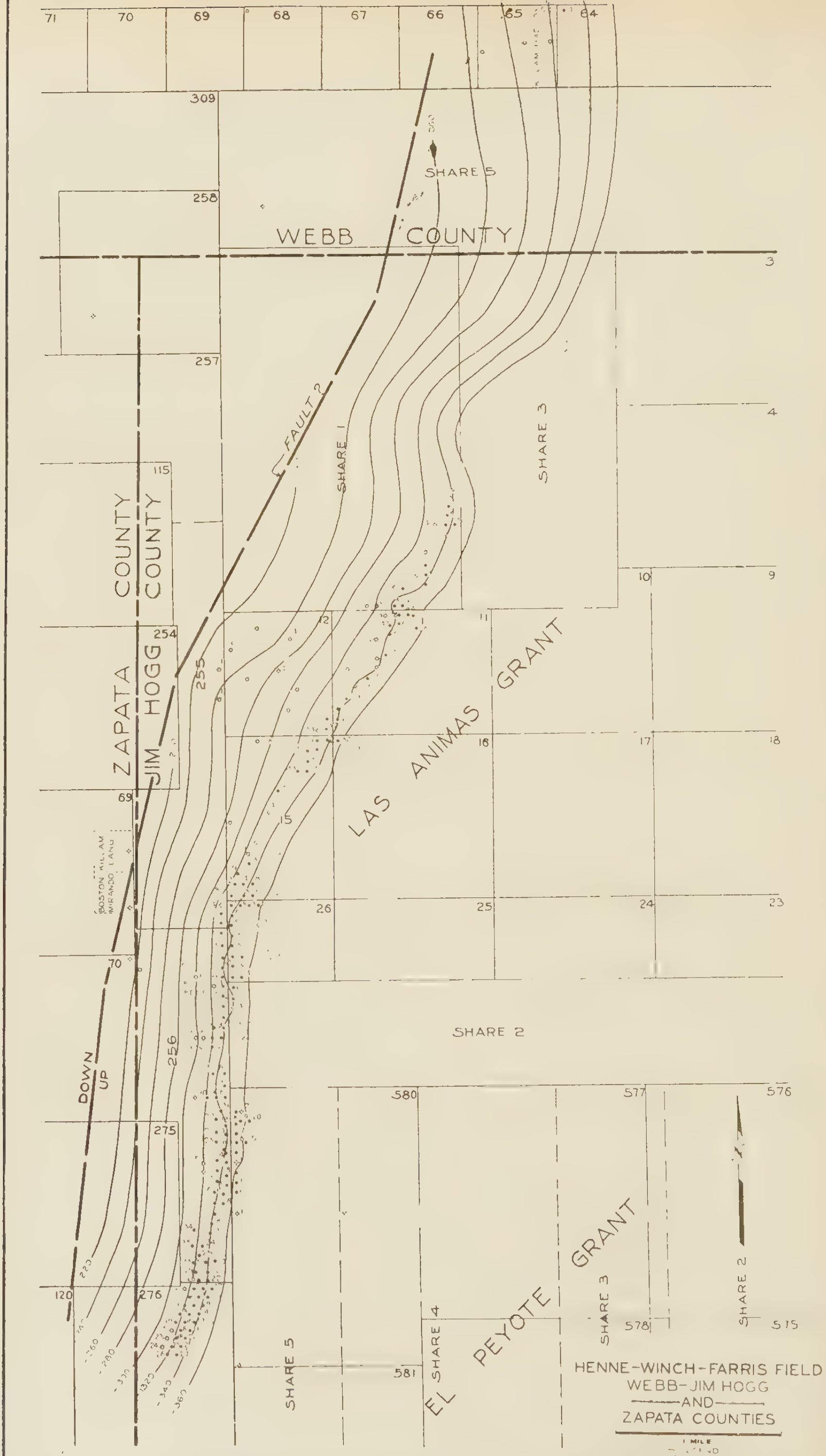


FIG. 6.—Map of Henne-Winch-Fariss field, Webb, Jim Hogg, and Zapata counties, Texas, showing fault. Contours on the Mirando sand.

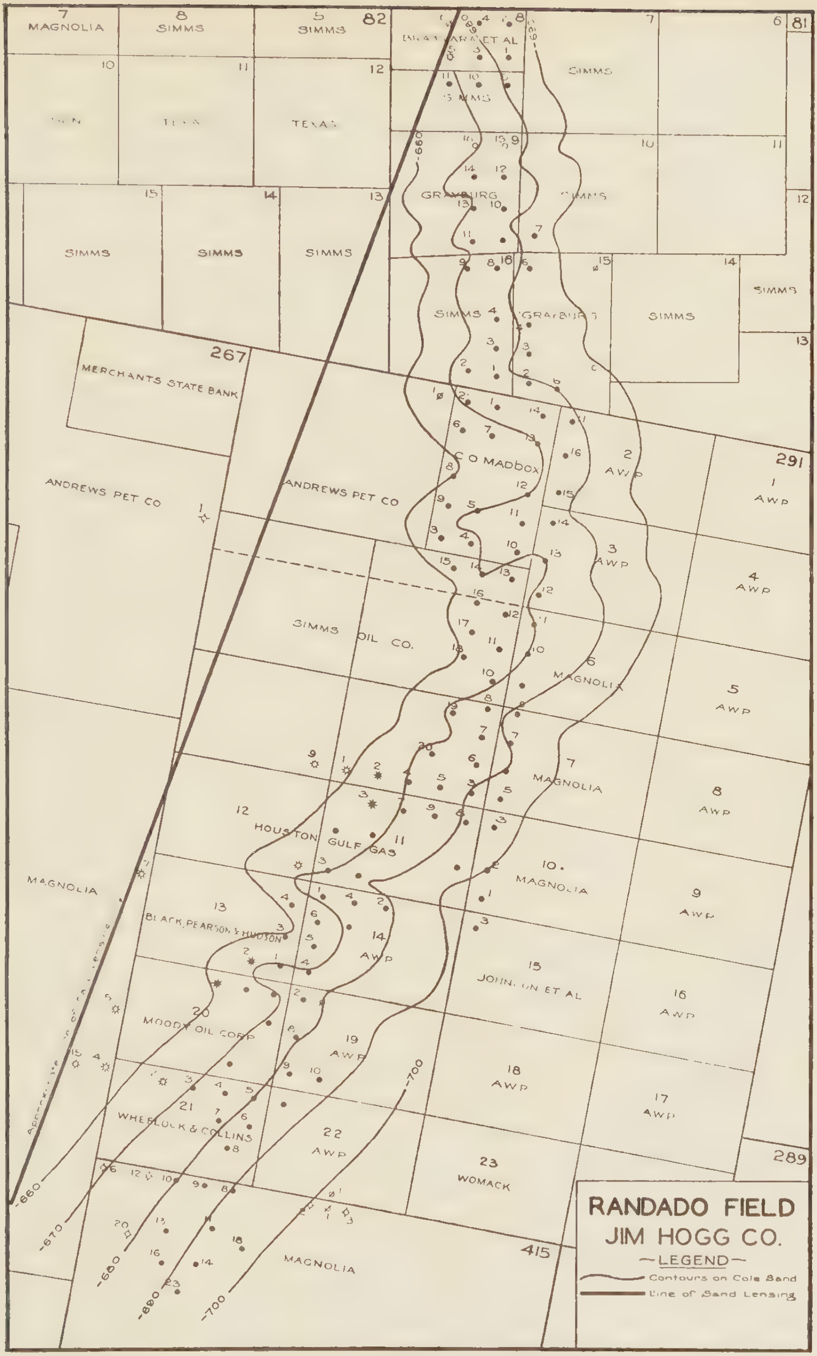


FIG. 7.—Map of the Randado field, Jim Hogg County, Texas, showing line of sand lensing. Contours on the Cole sand.

The lensing of the Cole sand under conditions similar to those described in the Cole field is the controlling factor of accumulation. A broad nosing is evident in Figure 7, affording closure at the edge of the sand body at both the north and the south edges of the field. The Cole sand is not present west of this field.

THE SCHOTT-AVIATOR FIELD

The discovery well in the Schott-Aviator field, which is located in Webb County, south of Mirando City, was completed December 10, 1921. Structurally, these two fields may be considered as one, with faulting as the primary cause of accumulation. Oil is obtained at depths of 1,600–1,700 feet in the Mirando sand, and is 21° Bé. gravity. In the Schott field six wells are also producing 42° Bé. oil from the Schott sand at 1,900 feet, approximately 300 feet lower in the section than the Mirando sand, Yegua in age. These two fields together have produced 8,000,000 barrels of oil, or more than half the total production of the district.

REISER GAS FIELD

The Reiser gas field is in Webb County at the town of Reiser on the Texas-Mexican Railway. It is the oldest field of the district, some shallow gas wells having been completed as early as 1911. Several gas sands are encountered at depths ranging from 400 to 800 feet, probably basal Fayette in age. Several deep tests have encountered oil showings in the Cook Mountain formation, but no commercial oil production has yet been found. At present all the gas wells in the field are abandoned.

JENNINGS GAS FIELD

The Jennings gas field is in Zapata County, about 21 miles south of Mirando City. This field was discovered in 1914, and for several years supplied gas to the city of Laredo through the Border Gas Company line. The greater part of the gas has been obtained from a sand at 1,300 feet in the basal part of the Fayette. Recently several large gas wells have been completed at 1,900 feet in a sand that is correlated with the Webster sand of the Carolina-Texas field. Good showings of oil and gas have been found in sands from 3,800 to 4,000 feet in two wells. The age of these sands is not definitely known, by they are considered as basal Mount Selman.

CHARCO-REDONDO FIELD

The Chardo-Redondo shallow oil field is located in Zapata County, 20 miles southwest of Randado. Small oil wells are found in this field at

a depth of 160 feet. Approximately 60 wells have been drilled and are producing a total of 47 barrels per day. Although very little information is available on structural conditions or age of the producing horizons, sand lensing appears to afford the reservoir for the accumulation of the oil.

TYPES AND SOURCES OF PETROLEUM

The following are analyses of oil from different fields of the district.

ANALYSES OF OIL, LAREDO DISTRICT

COLE FIELD (Cole Sand, Depth 1,750 Feet)

Gravity	18.4° Bé.	Flash	240
Paraffin	.04 per cent	Viscosity	187/100
Sulphur	.22 per cent		

AVIATOR FIELD (Mirando Sand, Depth 1,700 Feet)

Gravity	21.1° Bé.	Flash	215
Paraffin	.13 per cent	Viscosity	92/100
Sulphur	.19 per cent		

CAROLINA-TEXAS FIELD (Webster Sand, 2,600 Feet)

Gravity	33.0° Bé.	Flash	120
Paraffin	?	Viscosity	42/100
Sulphur	.12 per cent		

CAROLINA-TEXAS FIELD (Carolina-Texas Sand, Depth 3,000 Feet)

Gravity	41.5° Bé.	Flash	below 100
Paraffin	1.36 per cent	Viscosity	33/100
Sulphur	.04 per cent		

The oil in the Laredo district may be divided into two classes according to gravity: (1) the low-gravity oils of the Fayette formation, and (2) the high-gravity oils of the Cook Mountain formation. Evidence points to two distinct sources of the oil, and the difference in gravity is attributed to different conditions of origin.

The Fayette formation is partly marine and partly continental in origin. Both the Cole and the Mirando sands consist of zones of alternating sand and shale beds. Above and below these zones, and in places within the zones, is a large amount of lignite and lignitic shales indicating shallow-water deposition. Beds of oyster shells are also found within these zones, indicating marine conditions. The Cole and Mirando sand horizons which seem to have originated under similiar conditions were deposited in an advancing sea on a comparatively flat surface. These con-

ditions were favorable for the growth of various organisms and animal life, as is evidenced by thick beds of oyster shells and other fossils.

Therefore the producing horizons of the Fayette show a transition between marine and continental deposition. A great increase in red shale is noticed west of the productive area, although eastward more typically marine beds are found. It is possible that the Fayette formation, where encountered farther eastward in its more marine phase, contains greater amounts of oil than in the area under discussion.

The large amount of clay and volcanic material in the Fayette would seem to preclude the possibility of extensive vertical migration of oil except along fractures. Oil-saturated cores and small showings of gas and oil, particularly in the Mirando sand, have been found throughout the district in areas that show no indication of faulting or fracturing. Therefore the conclusion is reached that the oil originated within the horizon in which it is found, and has not migrated upward along fault planes from lower source beds.

The black carbonaceous shales of the upper Cook Mountain formation are considered as the source of the gas and high-gravity oil of the Webster and Carolina-Texas sands. As in the Fayette horizons, lateral migration appears to have been more important than vertical migration in the accumulation of the oil and gas in the reservoir sands.

NIGGER CREEK FIELD, LIMESTONE COUNTY, TEXAS[1]

LEON J. PEPPERBERG[2]
Columbus, Ohio

ABSTRACT

The Nigger Creek oil field is worthy of description because it is the first commercial pool to produce Woodbine sand oil from a fault structure up-dip from the prolific Woodbine fields in the Mexia-Powell fault zone of east-central Texas. The field is located in the *graben* between the Mexia-Powell fault and the Balcones fault. It contains 170 productive acres, 79 producing wells, and in two years, since discovery, has produced 2,690,000 barrels of oil, or 15,823 barrels per acre, from a fine-grained soft sand having a maximum thickness of 27 feet and an average pay thickness of about 16 feet. The depth of oil sand ranges from 2,800 to 2,850 feet below the surface. The subsurface structural relief is 35 feet, and the oil-water contact was 2,360 feet below sea-level. The fault plane dips 43° from the surface to the Austin chalk, flattens as it passes through the chalk, and in some parts of the field it dips as low as 15° where it cuts the Woodbine sand. The surface displacement of the fault is 260 feet, and the displacement in the Woodbine sand exceeds 500 feet. The drainage area tributary to this field is limited by the Mexia and other faults located within 2¾ miles toward the east (down-dip). Probably upward migration along the fault zone, horizontal migration across the fault, and migration up-dip, all contributed to the accumulation in this structure. The oil has a gravity of 40° API., contains 0.27 per cent sulphur and 39.9 per cent gasoline. Although the field was overdrilled, it returned the cost of leases, development, and operating expense plus 37 per cent profit in two years.

INTRODUCTION

The Nigger Creek field in Limestone County, Texas, is worthy of special reference, since it is the first commercial pool to be discovered producing Woodbine oil from a fault structure, parallel with and up-dip from the prolific Woodbine fields developed in what is known as the Mexia-Powell fault zone of east-central Texas.[3]

This field is also of interest because it is the only producing structure of the Mexia-Powell type which is clearly exposed at the surface.

Because the stratigraphy, structure, and general characteristics of the Mexia-Powell fault fields are described in several publications,[4] they will be touched but briefly in this paper.

[1] Title presented before the Association at the Tulsa meeting, March 25, 1927. Manuscript received by the editor July 10, 1928.

[2] Columbia Engineering and Management Corporation, Columbus, Ohio. Formerly consulting geologist, Dallas, Texas.

[3] F. H. Lahee, "Oil and Gas Fields of the Mexia and Tehuacana Fault Zones, Texas," this volume, pp. 304–388.

[4] F. H. Lahee, "Comparative Study of Well Logs on the Mexia Type of Structure," *Amer. Inst. Min. and Met. Eng.*, Vol. 71 (1925), p. 1329. F. Julius Fohs and H. M. Robinson, "Structure and Stratigraphic Data of the Northeast Texas Petroleum

LOCATION AND EXTENT

The Nigger Creek field is located about $2\frac{3}{4}$ miles west of and almost parallel with the Mexia field, Limestone County, Texas. It lies west of Nigger Creek and north of Navasota River (Fig. 1).

The productive area in the Woodbine sand is defined. It is 7,600 feet long, has a width of 1,300 feet, and contains 170 acres. The trend of the field is N. 32° E.

HISTORY OF THE FIELD

Since the discovery of the Mexia oil field on November 20, 1920, by the Humphreys Oil Company under the advice of F. Julius Fohs, eight fault-line oil and gas pools have been developed in the Woodbine sand. All of these fields are located along the so-called Mexia-Powell fault zone.

Several wells have been drilled east and west of the main fault. These were referred to as "inside wells" if located up-dip (west) from the main fault, or as "outside wells" if located down-dip (east) from the Mexia-Powell zone.

Wells drilled up-dip from the main fault received scant attention from the oil fraternity, because it was the consensus of opinion that the oil migrated up the dip to the known pools. It was assumed that since the major pools were so prolific, it was unreasonable to believe that the strata could contain sufficient oil to supply commercial accumulations in areas near by, up the dip. The major folds were supposed to act as dams which shut off migration westward beyond their productive limits, and in consequence of this widespread belief, favorable geologic structures, similar in type to that at Mexia, located in the down-dropped block or *graben* which lies west of the Mexia fault, with the downthrow on the west, and east of the Balcones fault zone, from 30 to 40 miles farther west, with the downthrow on the east, were considered of no value.

Prior to 1924 several Woodbine sand dry holes were drilled west and southwest of the Mexia field. One of these, drilled by Witherspoon *et al.*

Area," *Econ. Geol.*, Vol. 18 (1923), p. 709. W. E. Pratt and F. H. Lahee, "Faulting and Petroleum Accumulation at Mexia, Texas," *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 7 (1923), p. 226. George C. Matson, *U. S. Geol. Survey Bull. 629* (1916). F. H. Lahee, "The Currie Field, Navarro County, Texas," *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 7 (1923), p. 25. George C. Matson and O. B. Hopkins, "The Corsicana Oil and Gas Field, Texas," *U. S. Geol. Survey Bull. 661* (1917). H. B. Hill and C. E. Sutton, "Summarized Engineering Report on the Powell Field, Navarro County, Texas, with Special Reference to Water Problems and Corrective Work," *Amer. Inst. Min. and Met. Eng., Petrol. Division, Petroleum Development and Technology in 1926*, p. 297. L. J. Pepperberg, "Oil Possibilities Off the Main Fault," *Oil Weekly* (July 30, 1926), p. 54.

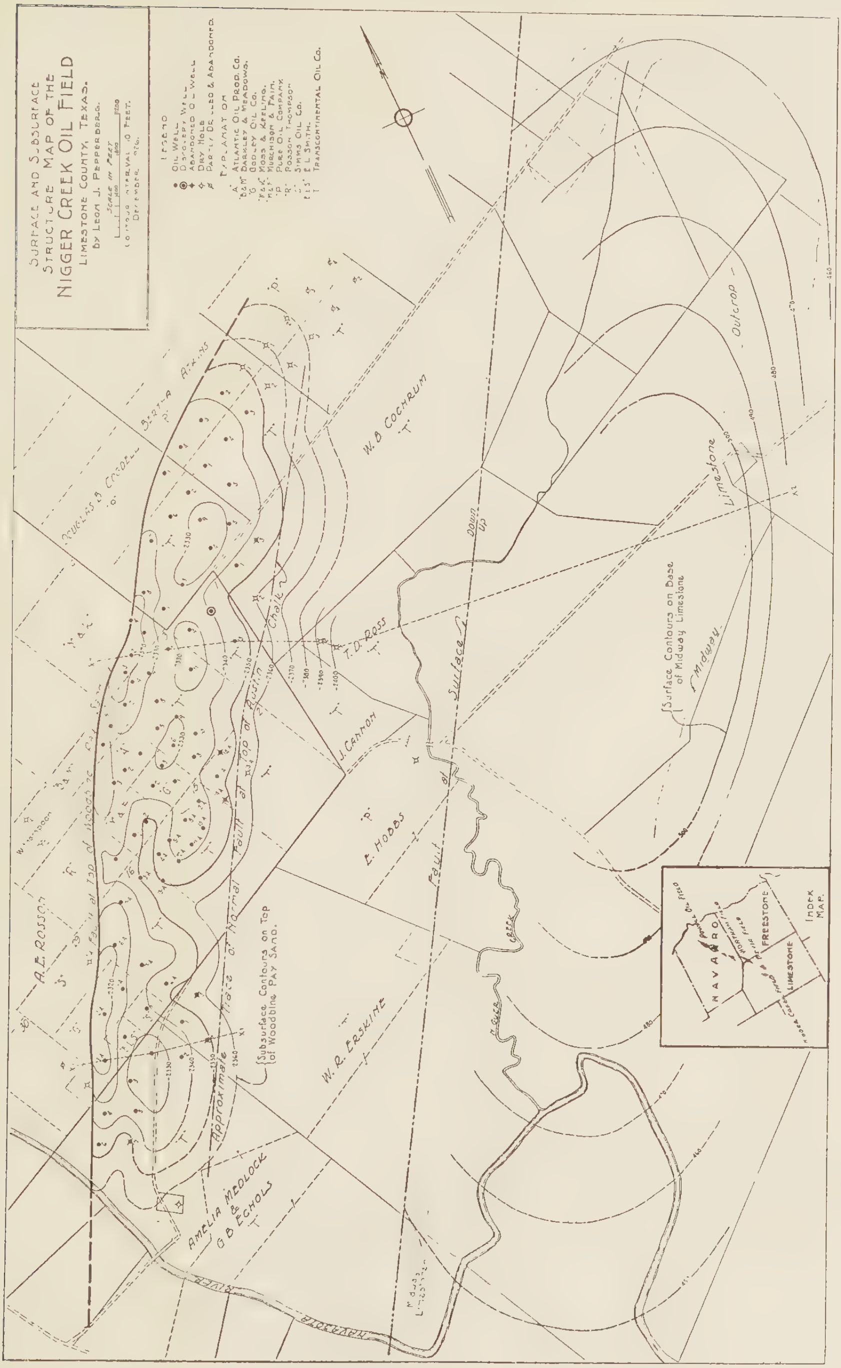

SURFACE AND SUBSURFACE
STRUCTURE MAP OF THE
NIGGER CREEK OIL FIELD
LIMESTONE COUNTY, TEXAS.
BY LEON J. PEPPERBERG.
LEGEND
OIL WELL
DRY HOLE
W. B. COCHRUM
T. D. ROSS
J. CANNON
E. HOBBS
W. R. ERSKINE
AMELIA MEDLOCK & G. B. ECHOLS
A. E. ROSSON
Approximate Trace of Normal Fault at Top of Austin Chalk
Subsurface Contours on Top of Woodbine Pay Sand.
Surface Contours on Base of Midway Limestone
Surface Fault
Limestone Outcrop
Midway
INDEX MAP.
NAVARRO
FREESTONE
LIMESTONE

FIG. I

on the Rosson farm, is located 500 feet west of the Nigger Creek productive area. The log of this well recorded considerable Woodbine sand. Its characteristics were similar to those of the Mexia field. A large volume of salt water was encountered in this well, and a small amount of black oil. The Midway limestone is exposed on the surface at this location.

A shallow well drilled near the southwest end of the Cochrum farm penetrated the Midway lime. Three other shallow wells, one on the east end of the Ross farm, the others along the northeast side of the Cochrum farm, did not encounter Midway limestone. From 2,000 to 2,500 feet east of the last-mentioned wells the Midway limestone crops out 50 feet above the bed of Nigger Creek (Fig. 2).

The logs of the wells mentioned and the outcrops of Midway limestone both east and west of Nigger Creek afforded the data from which the location, trend, and displacement of the surface fault of the Nigger Creek structure were determined (Figs. 1 and 2).

An intensive study of conditions along the Mexia-Powell fault zone, with special reference to structure, source, migration, and accumulation of oil convinced the writer that a test well would be justified up the dip from developed fields if a structure could be located where the theoretical requirements could be proved before a test was recommended.[1] During August, 1924, Heath M. Robinson[2] suggested Nigger Creek as meeting the particular requirements sought and assisted the writer in mapping the district.

The conditions found justified the recommendation of a test well, but efforts to induce operators to drill the structure were unsuccessful until early in 1925, when W. E. Wrather[3] became convinced of the possibilities of production on an up-dip fault. Wrather presented the proposition to the Transcontinental Oil Company and induced them to drill the structure.

On July 8, 1926, the Transcontinental Company's Rosson No. 1 was completed at a depth of 2,846 feet in the Woodbine sand with an initial production of 2,800 barrels. The well flowed steadily. There was no water. The corrected gravity of the oil was 39.9° Bé. Its temperature was 97°.

On July 20, 1926, Transcontinental's Cochrum No. 1 was completed with an initial flow of 4,000 barrels per day. Owing to poor fittings and

[1] J. P. D. Hull, "Discovery of Nigger Creek Oil Pool, Limestone County, Texas," *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), p. 997.

[2] Consulting geologist, Dallas, Texas.

[3] *Ibid.*

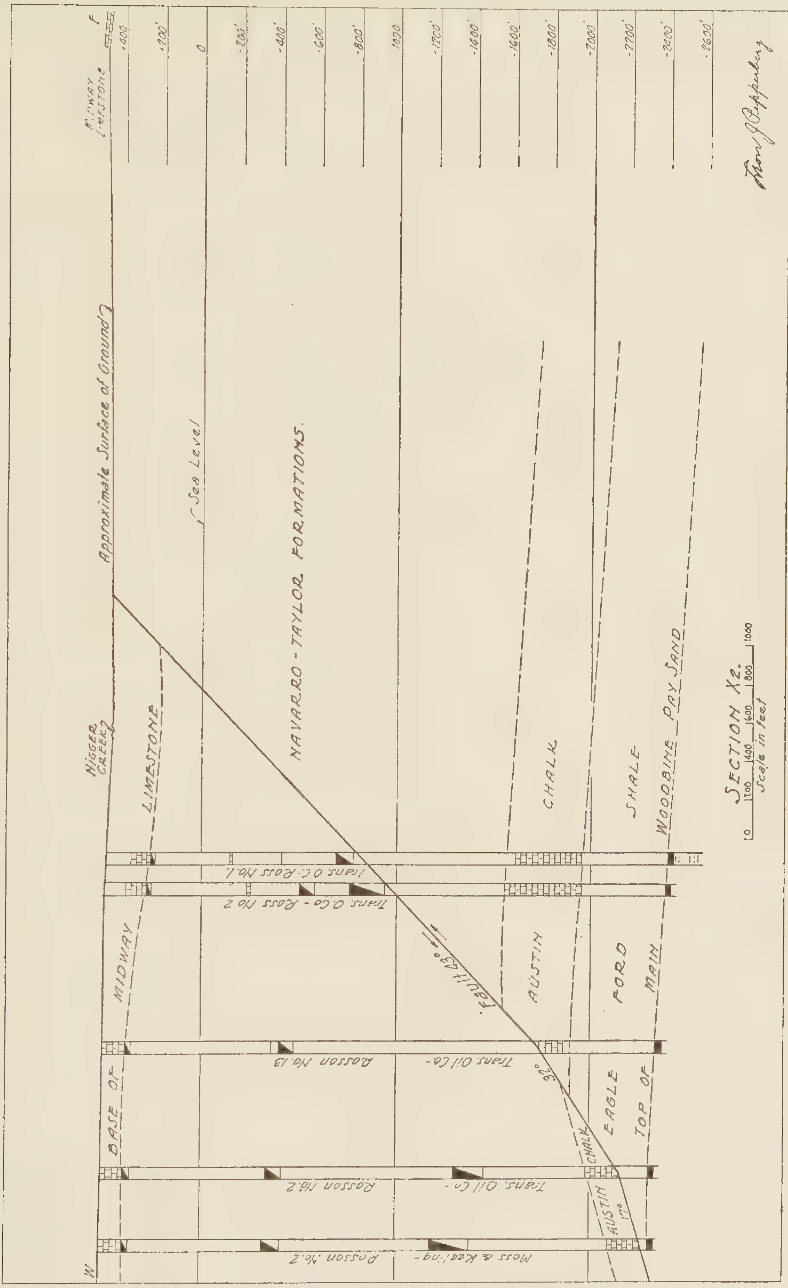


FIG. 2.—Section showing surface fault and thickness and sequence of formations in Nigger Creek field. Location of section is shown in Figure 1.

connections it was shut in and killed. When finally cleaned out, it flowed and pumped 850 barrels per day.

On July 26 the flow of the discovery well Rosson No. 1 had declined to 2,399 barrels per day. On the same date there were eighteen rigs and derricks, twenty locations, five drilling wells, and two completions in the field.

The field produced 539,995 barrels of pipe-line oil between July 8 and September 10 from 37 wells, and a total of 1,585,470 barrels from 72 producing wells to January 1, 1927. The peak production was 22,085 barrels per day from 33 pumping and flowing wells. This was reached September 7, two months after the discovery well was completed.

GEOLOGY

As previously mentioned, the Midway limestone of Eocene age forms conspicuous outcrops both east and west of Nigger Creek. It consists of a gray to tan fossiliferous, siliceous limestone about 100 feet thick underlain by about 35 feet of sand and sandy shale. The latter member weathers into a yellowish sandy soil.

An unconformity separates the Midway from the underlying Upper Cretaceous, Navarro-Taylor formations.

The areal distribution of the Midway limestone east of the Nigger Creek surface fault is shown in Figure 1. The geologic sequence and thickness of the Upper Cretaceous formations are indicated on the accompanying geologic cross sections (Figs. 2 and 3).

Geologic structure.—The Nigger Creek structure lies $2\frac{3}{4}$ miles west of, and almost parallel with, the Mexia structure. It is located in the *graben* between the Mexia-Powell zone and the Balcones fault.

Between Nigger Creek and the Mexia field, along Navasota River, there is surface evidence of two faults, one with a downthrow toward the east of about 50 feet, the other having a displacement of approximately 75 feet with the downthrow toward the west. These faults are approximately 1 mile apart. The westerly fault, having the greater throw, is approximately 1 mile east of the southwest end of the Nigger Creek fault.

These faults apparently die out near Navasota River. They are poorly developed north of this stream. No attempt was made by the writer to map the surface detail of these displacements south of the river.

For all practical purposes the gap between the northeast end of the Groesbeck structure and the southwest end of the Mexia field, along Navasota River, may be considered a synclinal area. The Nigger Creek structure is situated almost directly west of and opposite this gap.

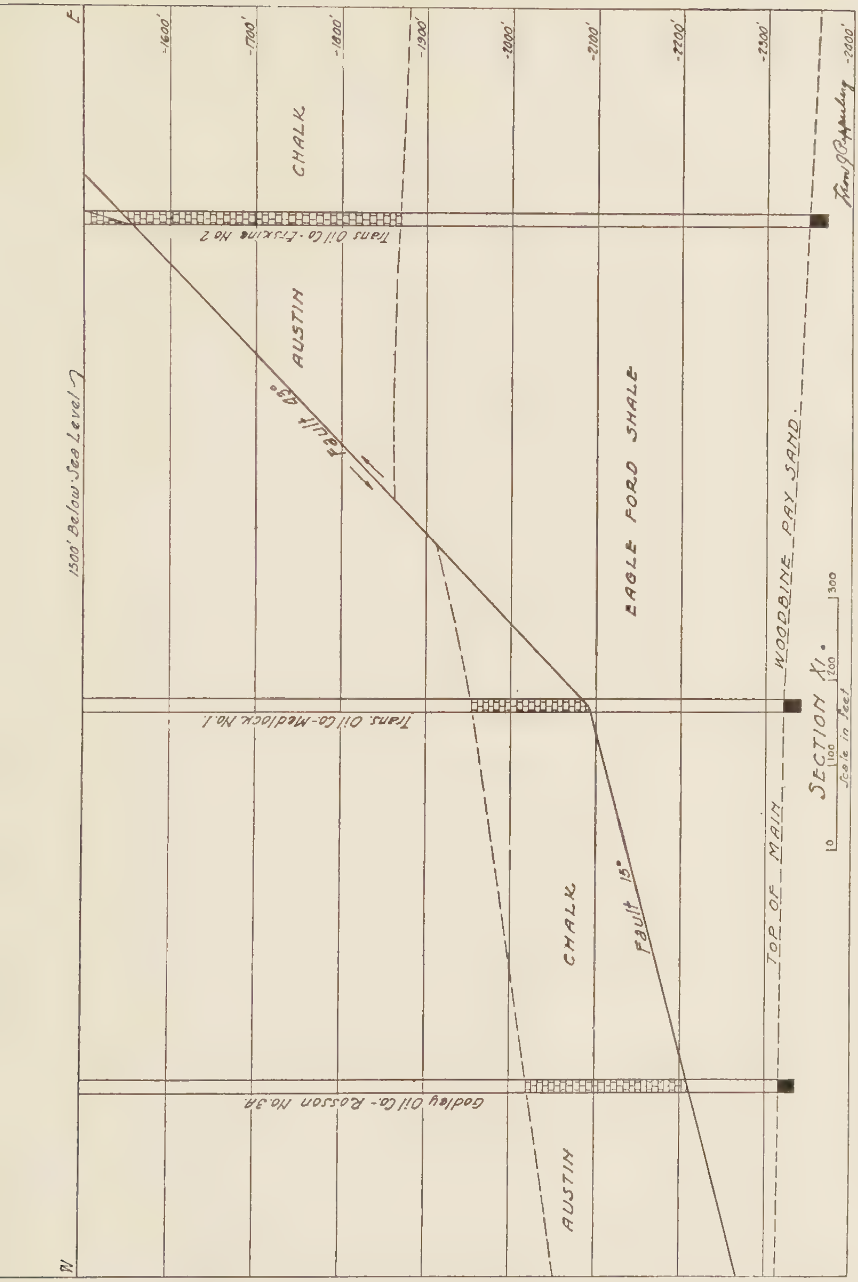


FIG. 3.—Section showing subsurface fault in Nigger Creek field. Thickness in feet. Location of section is shown in Figure 1.

The relation between the surface and subsurface geologic structure of the Nigger Creek field is shown on the map by surface contours on the base of the Midway limestone as the key bed and subsurface contours on the top of the Woodbine pay zone.

East, northeast, and northwest dips, at the northeast end of the surface deformation, are plainly visible in the Midway limestone. These form a perfect closure against the surface fault 4,000 feet northeast of the producing area.

The surface closure at the southwest end of the fold is based on one small outcrop of Midway limestone near Navasota River.

Contours for the southwest third of the surface structure are hypothetical due to the lack of outcrops of the key bed.

The western limit of the producing area is determined by the fault in the Woodbine sand. The trace of this fault, the subsurface contours, and the trace of the fault at the top of the Austin chalk are based on well-log data.

The most prolific area is located 4,000–5,000 feet due west from the highest part of the surface structure.

The structural relief at the surface is 50 feet. The producing area of the subsurface structure has a relief of 35 feet.

The fault is of the normal type with the downthrow toward the west. In the Midway lime at the surface its displacement is 260 feet. The displacement at the top of the Austin chalk is 360–500 feet, and at the top of the Woodbine sand it is 500–575 feet.

The fault dips 43° from the surface to the top of the Austin chalk. It flattens as it passes through the chalk, and in some parts of the field has as low an angle as 15° from the horizontal where it cuts the Woodbine sand.

The fault is not a simple plane, but consists of a faulted zone which ranges from a few feet to 200 feet in width. The closure in the subsurface structure at the top of the pay zone along the fault is due to drag.

OIL

Occurrence.—The reservoir of the Nigger Creek field consists of one producing zone near the top of the Woodbine formation. This sand is 2,800–2,850 feet below the surface. It has a maximum thickness of 27 feet, is fine-grained, soft, loosely cemented, and has a porosity of 25 per cent. Owing to the low relief of the structure, only those wells near the fault encountered the full thickness of the sand saturated with oil. The average thickness of the pay zone was about 16 feet.

A small amount of gas accompanied the oil. When tested, this showed

3 to 8 gallons of gasoline per thousand cubic feet. The chief force which caused the wells to flow was the hydrostatic head of the edge water. The original water-oil contact was at −2,360 feet. The water bounded the productive area and constituted both edge and bottom water near the −2,360-foot contour.

Analysis.—The character of the Nigger Creek oil is indicated in the analysis by the United States Bureau of Mines (Table I). The day this sample was taken the well produced 250 barrels.[1]

Source.—A study of conditions in and adjacent to the fault zone fields of east-central Texas strongly suggests that it is as reasonable to assume that a large part of the oil could have migrated up the fault planes from deep source beds, or across fault planes from source beds in juxtaposition with reservoir strata, as it is to assume that it migrated up the dip of the strata in which accumulation is found. In all probability upward migration along fault planes, horizontal migration across faults, and migration up-dip, all contributed to the accumulation of pools in these structures.

A comment frequently expressed by men familiar with conditions surrounding the major fault-line pools is the scarcity of showings of oil in the Austin chalk which overlies the Eagle Ford shale. The Eagle Ford has all the earmarks of a source bed; in fact, oil springs are common along its outcrop at certain localities.

Numerous cores of Austin chalk taken from wells in the Powell field showed slight traces of oil, or none whatever, even at locations adjacent to faults where the chalk was crushed and semiporous.

If the Eagle Ford shale, which overlies the Woodbine sand, is assumed to be the chief source bed for oil accumulations in the Woodbine, it was necessary for the oil to migrate downward into the sand, or, more likely, to migrate horizontally across the fault plane into the structural trap as it was being formed by movement along the fault zone.

The prolific production of the Luling field, which occurs in dolomitic limes belonging to the Edwards formation, is of Lower Cretaceous age; the Woodbine production of the Mexia-Powell fields, which is 350-500 feet higher stratigraphically, is of Upper Cretaceous age. The Luling production is associated with a series of faults similar in type to those at Mexia and Powell.

The oil found in the Humphreys Oil Company's Jones No. 1 at Kosse, Limestone County, is believed to have come from the Glen Rose member of the Trinity group. The Trinity is the lowermost member of Lower Cretaceous in this region. This well was drilled adjacent to a fault.

[1] *The Oil and Gas Journal* (February 24, 1927), p. 132.

TABLE I

Analysis of Nigger Creek Crude

The approximate summary of the analysis of this crude is as follows:

	Per Cent	Specific Gravity	API.	Viscosity
Light gasoline (end point 212° F.)	12.2	.682	76.0	....
Total gasoline and naphtha	36.9	.728	62.9	....
Kerosene distillate	11.5	.804	44.5	....
Gas oil	15.8	.849	35.2	....
Non-viscous lubricating distillate	10.4	.867–.893	31.7–27.0	50–100
Medium lubricating distillate	6.8	.893–.917	27.0–22.8	100–200
Viscous lubricating distillate	....	....	....	Above 200
Residuum	18.6	.956	16.5	....
Distillation loss	8.0	....	....	....

The detailed analysis of the sample of crude is as follows:

Sample No. 26,586: Texas, Nigger Creek Field, Limestone County

Woodbine sand	2,840–42 ft.	Saybolt Universal viscosity at 70° F.	42 sec.
Specific gravity	.825	Pour point	Below 5° F.
API. gravity	40.0°	Saybolt Universal viscosity at 100° F.	42 sec.
Per cent sulphur	.27		
Per cent water	Nil	Color	Brownish-green

DISTILLATION TEST

BUREAU OF MINES—HEMPEL METHOD

Air distillation. Barometer, 749 mm. First drop, 33° C. (91° F.)

Temperature °C.	Per Cent Cut	Sum per Cent	Specific Gravity of Cut	API. of Cut	Viscosity at 100° F.	Cloud Test °F.	Temperature °F.
Below 50	2.7	2.7	....	....	....	....	Below 122
50–75	2.1	4.8	.662	82.2	....	....	122–67
75–100	7.4	12.2	.695	72.1	....	....	167–212
100–125	5.7	17.9	.723	64.2	....	....	212–57
125–50	7.2	25.1	.742	59.2	....	....	257–302
150–75	5.8	30.9	.762	54.2	....	....	302–47
175–200	6.0	36.9	.778	50.4	....	....	347–92
200–225	5.1	42.0	.795	46.5	....	....	392–437
225–50	6.4	48.4	.812	42.8	....	....	437–82
250–75	6.3	54.7	.830	39.0	....	....	482–527

VACUUM DISTILLATION AT 40 MM.

Temperature °C.	Per Cent Cut	Sum per Cent	Specific Gravity of Cut	API. of Cut	Viscosity at 100° F.	Cloud Test °F.	Temperature °F.
Below 200	4.9	4.9	.859	33.2	42	20	Below 392
200–225	7.3	12.2	.864	32.3	48	45	392–437
225–50	5.2	17.4	.883	28.8	65	60	437–82
250–75	4.5	21.9	.892	27.1	97	78	482–527
275–300	4.8	26.7	.909	24.2	193	92	527–72

Residuum, per cent	18.6	Distillation loss	Nil
Carbon residue or residuum, per cent	8.6	Carbon residue of crude, per cent	1.6

In the Mexia-Powell region, below the prolific Woodbine pools, the Edwards and Trinity, both possible oil-bearing zones, are present. Other intermediate strata which are oil- and gas-bearing at some localities, and which are capable of being reservoirs under proper structural and sedimentary conditions, also underlie this district.

Oil which accumulated in these lower strata or which was generated in beds interlocated with or adjacent to them or in beds older than the Cretaceous could migrate up the fault planes in this region to be trapped in favorable structures nearer the surface.

The fact that Nigger Creek has produced 15,823 barrels of oil per acre, or approximately 1,055 barrels per acre-foot of pay sand, in two years indicates that the sand was highly saturated.

If the two faults previously mentioned, which are located between the Nigger Creek and Mexia structures, are important structurally, they will restrict the drainage area serving Nigger Creek and act as dams to check migration up-dip, westward, to this structure.

If this assumption is correct, the greater part of the oil in Nigger Creek must have migrated horizontally across the fault, while the structure was forming, or up the fault zone from deeper source beds.

Development, production, and value.—Altogether 94 wells were drilled or partly drilled in the Nigger Creek area. Of these, 79 were producers and 15 dry holes. Five of the dry holes were outside the defined possible oil area when drilling was begun.

Twenty-nine unnecessary oil wells were drilled within the producing area, which could have been efficiently drained by 50 producers. In June, 1928, 45 wells were producing a total of 650 barrels of oil per day.

The productive area of the field was 40 per cent overdrilled from an economic standpoint.

Some of the excess drilling was due to necessary offsets, to protect leases from drainage, but a large part was due to mismanagement.

In addition to overdrilling the area, men in charge of some properties were not conversant with problems and conditions common to fault-line fields. On this account the casing was set several feet too low in many wells, thus shutting off the top and most prolific part of the sand. Other wells from which excellent oil-saturated cores were taken were drilled too deep into water, even after the water-level had been definitely determined.

The rapidity with which the field was developed made possible the marketing of 1,585,470 barrels of oil during the latter half of 1926, and the posted price for this grade of crude was \$2.34 per barrel. The value of this oil partly offset the cost of the excessive drilling.

Ten companies and individual operators developed the Nigger Creek field. Conclusions drawn from a study of cost data and results are of interest.

GROSS PRODUCTION, NIGGER CREEK FIELD

	Barrels
July–December, 1926	1,585,470
January–December, 1927	972,290
January–June, 1928	132,240
Gross oil produced in two years	2,690,000

ACRE-YIELD AND WELL-YIELD

	Barrels
Area, 170 acres	15,823 (per acre)
Total wells drilled, 94	28,617 (per well)
Total oil wells, 79	34,050 (per well)
Necessary oil wells, 50	53,800 (per well)

On the basis of 79 oil wells, each served about 2 acres of the productive area; each of 50 wells would have efficiently drained 3 acres.

Value of oil.—The average price obtained for all oil produced in two years was $2.1068 per barrel, notwithstanding the fact that the present posted price is $1.34 per barrel.

	Produced	Value
Gross barrels	2,690,000	$5,667,292.00
$\frac{7}{8}$ W.I. barrels	2,363,750	4,958,880.50
$\frac{1}{8}$ Roy. barrels	336,250	708,411.50

Cost of development and operation.—These estimates are based on actual costs covering several well-managed leases in the Nigger Creek field. Oil-well costs include wells completed, lease equipment, and cost of lease. Production costs include all lease operating expense, replacements, taxes, insurance, and overhead.

Item	Cost
15 dry holes	$ 180,000.00
79 oil wells	2,130,000.00
Producing 2,690,000 gross barrels	1,291,200.00
Total cost development and operation	$3,601,200.00

	Balance
Value of seven-eighths of oil produced	$4,958,880.00
Total cost	3,601,200.00
Profit in two years	$1,357,680.00

The excessive investment in this field was paid out in two years and 37.7 per cent profit earned thereon. A few properties returned the investment plus 48 per cent profit. Others show as low as 20 per cent profit after the return of cost of development and operation.

RELATION OF ACCUMULATION TO STRUCTURE IN THE OIL FIELDS OF ARCHER COUNTY, TEXAS[1]

W. C. THOMPSON[2] and W. E. HUBBARD[3]
Wichita Falls and Amarillo, Texas

ABSTRACT

The oil district of Archer County consists of numerous small pools producing from sands in the Cisco (Pennsylvanian) at depths ranging from 900 to 1,700 feet. The oil produced ranges from 39° to 40° Bé., and drilling costs are low so that the area has been a profitable one, especially to independent operators. Production in the county is now about 25,000 barrels daily.

Oil is found in lenticular sand bodies which have been deposited on the axes of relatively low structures. The occurrence of sand on these high areas and its absence in the synclinal areas is thought to be due to a shallow sea advancing over a series of low folds which were partly represented by topography. Such conditions are thought to be sufficient to cause material to be eroded from these low hills, and sand and heavier material to be re-deposited in shallow water (along the high parts) while fine sand and silt would eventually sink in the deeper water.

The presence of shale containing land plants overlain by a marine sand in the producing zone indicates that the oil is indigenous to the producing horizons.

INTRODUCTION

This paper is largely an amplification of certain phases discussed in a previous paper by the same writers.[4] Much of the information dealing with general conditions has been briefly restated in this paper, and only that which has a definite bearing on the conclusions set forth has been discussed fully. The information on which the following conclusions are based was gained by a study of subsurface structure and also depositional conditions during Cisco time, as shown by well cuttings and samples from the outcrops.

The theories set forth herein may prove entirely inadequate to account for conditions of accumulation in Archer County, but are offered as one possible explanation of conditions encountered, and it is hoped

[1] Presented by title before the Association at the Tulsa meeting, March 26, 1927. Manuscript received by the editor, October 5, 1927.

[2] Geologist, Sun Oil Company.

[3] Superintendent, Amarillo district, Humble Oil and Refining Company.

[4] W. E. Hubbard and W. C. Thompson, "The Geology and Oil Fields of Archer County, Texas," *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 5, May, 1926.

that further research and discussion will produce a theory that will be satisfactory in every respect.

ACKNOWLEDGMENTS

A large part of the information in this paper is the result of an interchange of ideas between the writers and other geologists interested in the problems of Archer County and similar problems of other districts. Space will not permit a detailed acknowledgment of all these sources of help, but the writers especially desire to mention the following: F. H. Lahee and W. E. Pratt, chief geologists of the Sun Oil Company and the Humble Oil and Refining Company, respectively, for permission to publish this paper and for valuable criticism and encouragement; and R. B. Whitehead, A. J. Viets, and Virgil Pettigrew for contributions of subject matter and assistance in assembling material for the paper.

HISTORY

Oil was discovered in Archer County in 1911, but it was not until 1923 that the county became an important producer. During the latter year a daily production of about 15,000 barrels was attained, and since that time production has averaged about 30,000 barrels daily.

From the start of major development geologists have played an important part. At first surface structures were mapped in an effort to locate new pools, and while this method met with some degree of success, it has not been as useful as subsurface correlations, and at the present time subsurface mapping is used almost exclusively.

GEOGRAPHY

Archer County lies in the north-central Texas oil belt about midway between the eastern and western boundaries of the state and a short distance south of Red River (Fig. 1). It is bounded on the north by Wichita County and on the south by Young County, both of which are important producers of oil, coming largely from the same sand and under conditions similar to those in Archer County. Clay County lies on the east and Baylor on the west.

The land surface of Archer County is one of moderate relief, and there is little or no timber other than a growth of mesquite which covers a large part of the area. Elevations above sea-level range from 900 feet in the eastern part of the county to 1,300 feet in the southwestern part. Drainage is north and east through Wichita and Little Wichita rivers, and the west fork of Trinity River. The climate is semi-arid and most of the land is used for cattle raising.

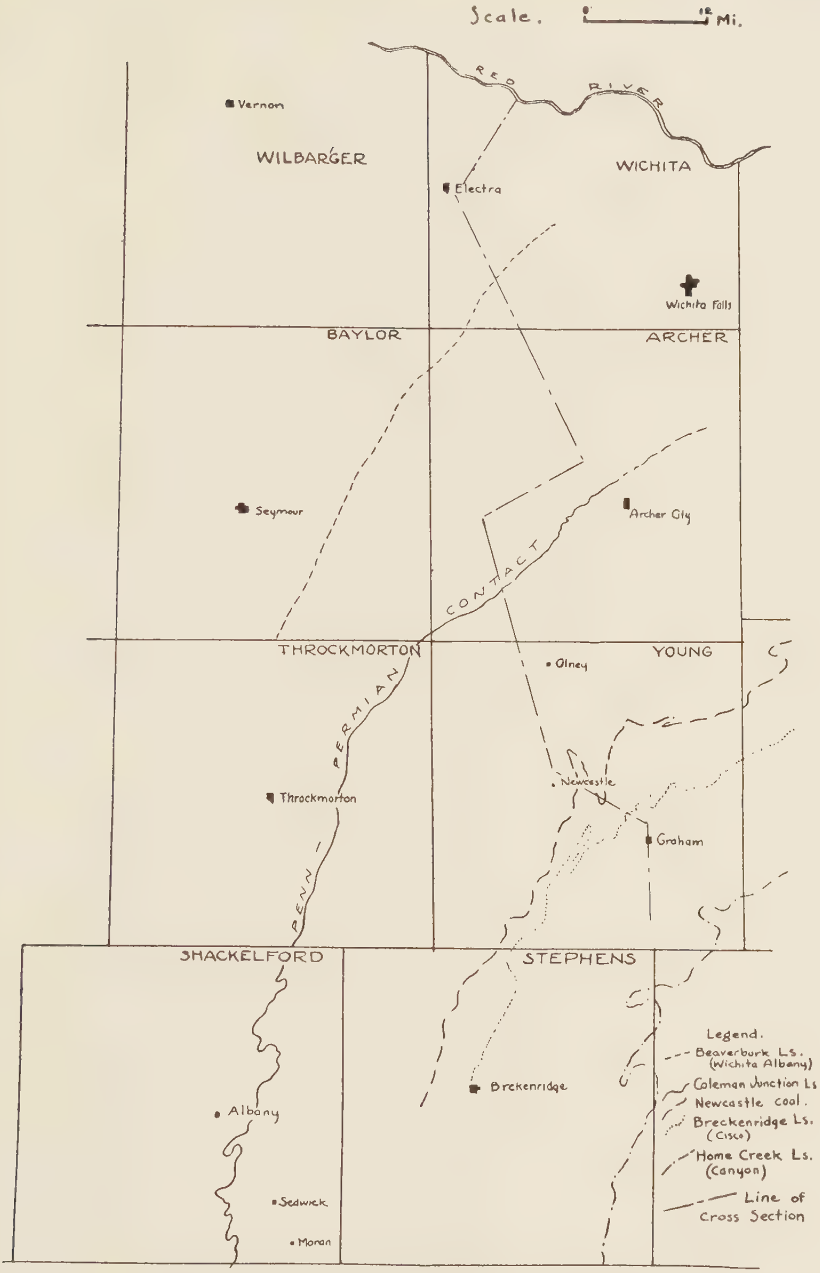


FIG. 1.—Map showing the Pennsylvanian-Permian contact and outcrop of other key horizons of north-central Texas.

STRATIGRAPHY

The accompanying columnar section (Fig. 2) shows the principal beds involved in the fields of Archer County. The main zones shown also extend into Young County on the south and Wichita County on the north.

Surface rocks in Archer County include about 400 feet of upper Cisco exposed in the southeastern part of the county (Fig. 1). In the remaining area are Permian rocks of the Wichita-Albany formation.

Upper Pennsylvanian and Lower Permian rocks in this district are so similar lithologically that no sharp dividing line can be drawn, and evidently the same conditions of sedimentation extended across the contact of the two systems. The generally accepted contact is that of the Coleman Junction limestone, since the latter is persistent and somewhere near the contact.[1]

Pennsylvanian rocks consist of beds of gray and white sand which grade locally into conglomerates interstratified with shales, mostly red, but in places light to dark gray. Westward and southwestward these beds grade into marine sediments consisting of darker shales and limestones.

Permian rocks above the Coleman Junction limestone consist of white and gray lenticular sands and red shales. The uppermost bed of this series in Archer County is the Beaverburk limestone which crops out in the extreme northwestern part of the county. The Wichita series also grades into marine beds toward the west and southwest, and the Beaverburk is probably a limy phase of some of the sands exposed in eastern Wichita County.

The Cisco formation underlying Archer County has several fairly continuous beds, at least according to zones which may be correlated rather reasonably with surface beds. There is a marked thickening of the Cisco, however, from southern Young County northward, so that the section penetrated in wells is greatly in excess of that measured at the outcrop.

There is also a change in sediments from the north to the south part of Archer County. Although in the fields of the former area only a few thin limestone beds are encountered, wells in the fields near the Young County line encounter several thick limestones between the Camp Colorado series and the Breckenridge limestone, thus making this part of the drilling somewhat difficult. The thickening of these limestones southward is similar to the change in character exhibited by the outcropping beds of the upper Cisco and lower Wichita and tends to indicate a source of sediments from the northeast.

[1] F. B. Plummer and R. C. Moore, *Univ. of Texas Bull. 2132* (1921), p. 190.

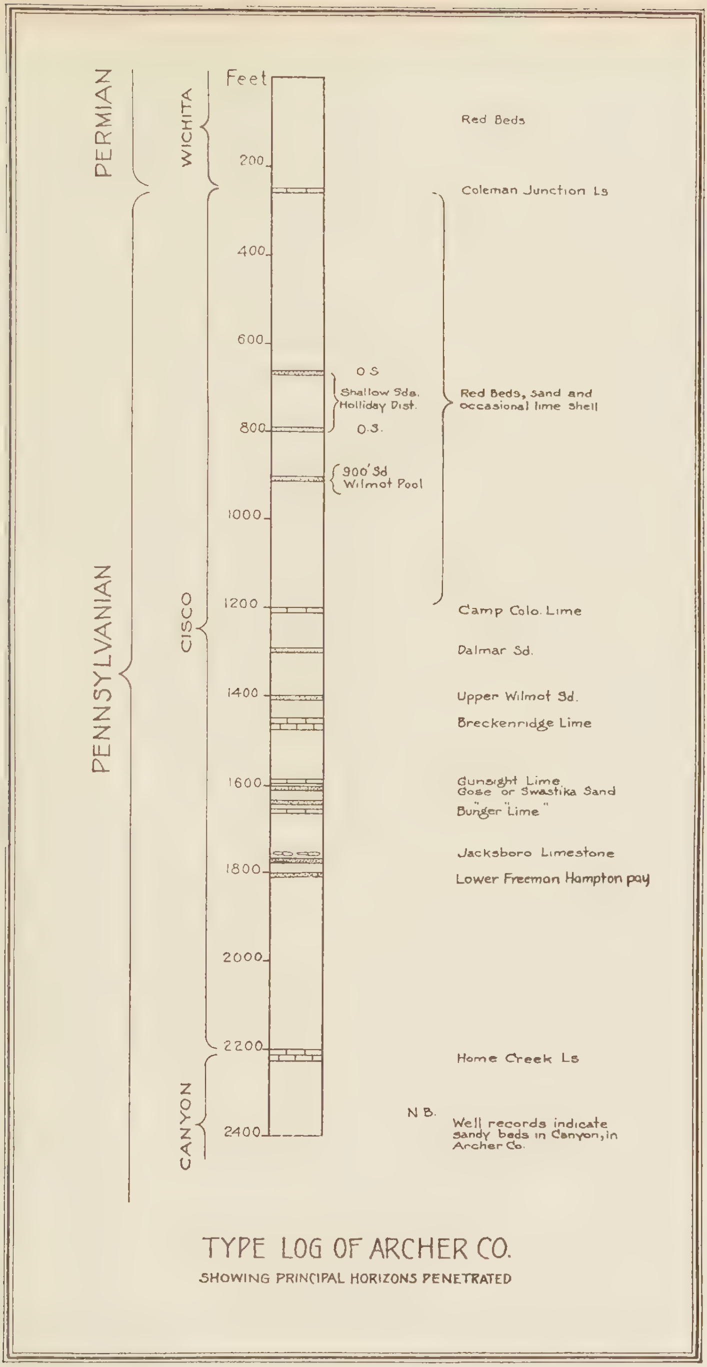


Fig. 2.—Type section of Archer County as shown in well logs, showing horizons penetrated.

PRODUCTIVE HORIZONS

Practically all of the oil in Archer County comes from the lower half of the Cisco formation (Fig. 2). These pay sands, although of common occurrence throughout the county, show very erratic deposition locally, and it is not uncommon to find dry holes in the midst of producing wells, or vice versa.

Texhoma-Gose sand.—The most important zone is the Texhoma-Gose "pay." The first oil discovered in Archer County came from this zone at a depth of 900 feet in the old Miller pool in southeastern Archer County. This pay is commonly referred to as the Swastika, Archer County, or Wilmot "pay," and the term "Gunsight sand" is also coming into general use. It is found at depths ranging from 650 feet in the extreme southeastern part of the county to 1,650 feet in the Freeman-Hampton pool. It is productive in almost every pool in the county. Wells from this sand are making more than 90 per cent of the total oil produced.

The Texhoma-Gose sand is throught to lie directly below the Gunsight limestone of the Cisco section. In most places there is a shale interval of 5–15 feet, but in some places the limestone, which ranges from 1 to 5 feet thick, grades directly into sand.

This pay sand is really a zone about 50 feet thick, and the sand may be found either in the upper or the lower portion. At several localities, but notably in the area north of the Ragle pool and southeast of Anarene, two distinct sands are found about 50 feet apart. The average thickness of sand encountered in wells is probably 6 or 7 feet, although in some places as much as 30 feet has been penetrated.

In some places the regular Gunsight horizon is represented by a porous limestone which produces in several areas. In such places the upper foot or two of the limestone is hard and unsaturated, but immediately below it is softer and porous. During the past year this saturated limestone has been found commercially productive in several areas, chief among which are the Logan pool and the Green area in the south-central part of Archer County west of Anarene. In several other areas of southern Archer County showings have been encountered and individual wells have produced from this limy phase of the Gunsight horizon.

OTHER SANDS

Besides the Texhoma-Gose "pay," several others have been important locally.

Lower Freeman–Hampton sand.—The lower Freeman–Hampton sand

is encountered at a depth of about 1,750 feet in the pool of the same name. It also produces in the Orton, Tad Wilson, Lyles, and Shappell pools, and has been tentatively correlated with the 1,750-foot sand in the K.M.A. pool and with the 1,900-foot sand at Electra. The top of the pay zone lies about 160 feet below the Texhoma-Gose horizon, and like it in many places consists of two beds about 40 feet apart and averaging about 8 feet thick.

Upper Wilmot sand.—The upper Wilmot sand produces in the Wilmot, Peterson, Sunshine, State, Oil Investment, Texhoma-Gose, Hudson, and Thomas pools, and is generally about 200 feet above the Texhoma-Gose horizon. It is not productive throughout as large an area as the deeper sand, nor is it as thick. The 1,050-foot sand of the Oldham pool may be either the equivalent of the upper Wilmot or the Dalmar sand.

Dalmar sand.—The Dalmar sand is productive at a depth of 1,000 feet in the Dalmar pool, and 1,100 feet in the Oil Investment area and from one well in the Texhoma-Gose field. It is found about 300 feet above the Gose sand.

The accompanying section (Fig. 2) shows other sands in which scattered production has been developed principally in the shallow field near Holliday. These sands are not very extensive and are even more erratic than the deeper zones.

Lower formations.—Only relatively few wells in Archer County have been drilled deep enough to give any idea about the formations below the Cisco.

In oil-producing counties on the south important production has been obtained from the Bend and Strawn (cross section, Fig. 3), and, more recently, the Canyon formation. Under fairly normal conditions these same formations or their equivalents may be expected to be present under Archer County, even though their lithologic character may by changed. Although these formations are important in view of their possibilities for deeper production, they do not have sufficient bearing on the present subject to justify further discussion.

NATURE OF SANDS

Archer County sands are normally even-grained, friable quartz sands. About 50 per cent of an average sample passes through a $\frac{1}{2}$–$\frac{1}{4}$ millimeter screen, and the remainder is about equally divided between grains ranging from $\frac{1}{8}$ to 1 millimeter in diameter. Previous statements of porosity gave an average for several sands tested as 22 per cent. This has been

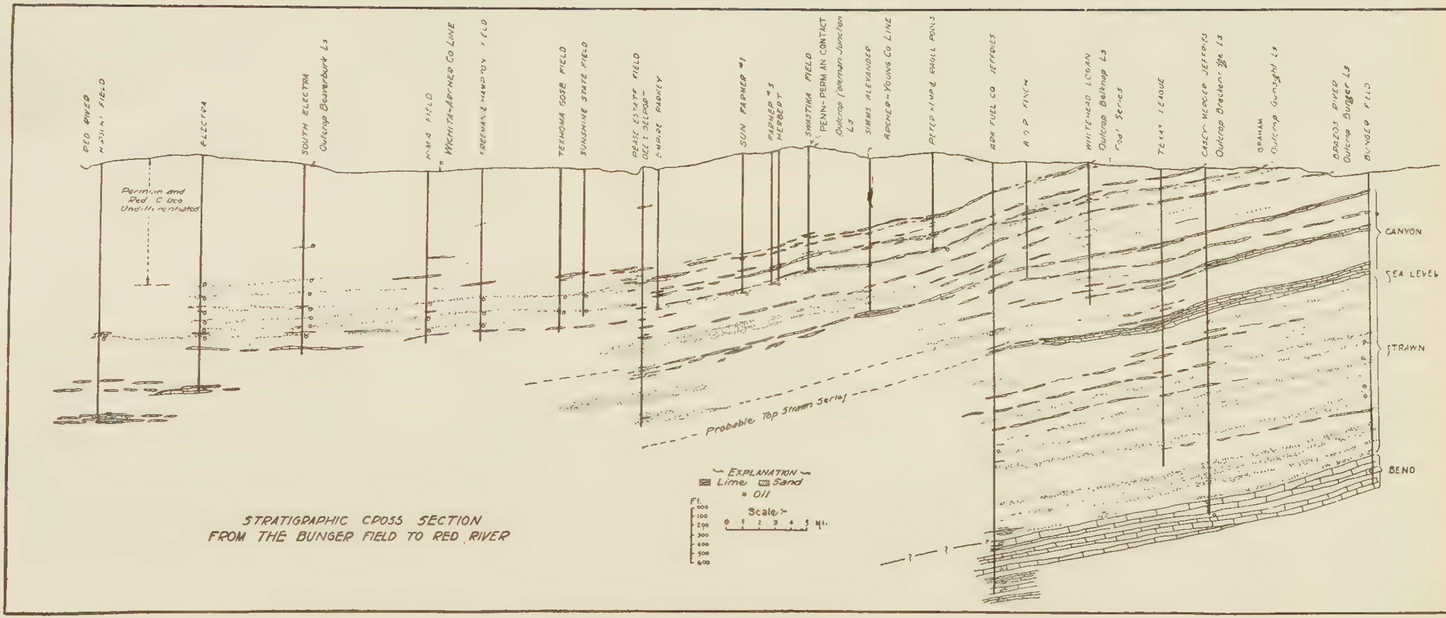


FIG. 3.—Stratigraphic cross section from Bunger field in Young County to Red River, showing relation of Cisco to other oil-bearing formations in North Texas.

checked by Bureau of Mines engineers,[1] who, using a different method, have arrived at a similar figure for a considerable number of type samples.

Statements regarding porosity and sand characteristics take into consideration only true sand samples.[2] Each field is in itself a separate sand lens, and toward the edges of fields the sand rapidly becomes intermixed with shale and finally grades into shale. Naturally porosity in such places will fall far below that of the main sand body.

Figures as to acre-yield are governed by the amount of acreage thought to be drained by a given well or the acreage that should be included in a given pool. This will naturally vary according to individual ideas, but considering the total producing acreage, the total production to date, with probable future production, and comparing this with actual determinations, it is thought that ultimate production per acre in Archer County should be about 7,000 barrels.

STRUCTURE

Regional structure. —Archer County lies along the projected axis of the Bend arch, and the rocks are evidently affected to some extent by this feature. The trends of stronger folding, however, seem to be more affected by the Red River arch, and the alignment of fields, although associated with higher parts of the Bend arch, show a northwesterly trend more or less parallel to the former. Apparently the structural features shown in the main Archer County pay zones, which are considerably above the beds involved in the folding of the Bend arch, are more closely related to the Red River arch.

Rocks of the whole area have an average dip of about 25 feet per mile northwestward, except in the northern part of Archer County, where northeast dips are noticed. The average strike of the Cisco beds is about N. 70° E. (Fig. 5).

Local structure. —Some folding may be observed in almost any area in Archer County where sufficient outcrops occur. These surface folds are as a rule small plunging anticlinal noses or terraces, generally without closure, but in places showing from 10 to 15 feet of reversal. Although some surface folding exists in the vicinity of many pools, the results of drilling in Archer County show that there is an entire lack of parallelism between surface and subsurface structures.

[1] H. B. Hill and C. E. Sutton. Acetylene tetrachloride method used. This method described in *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 10 (October, 1926), p. 931.

[2] Two samples of saturated lime from the main pay zones which were tested by W. E. Winn, chemist of Sun Oil Company, show porosities of 13 and 16 per cent.

Subsurface folds are of the same type as surface folds except that some of them have more closure and almost all of them show a more pronounced axis. Figure 4 and Plate 1 show the type of subsurface structures of

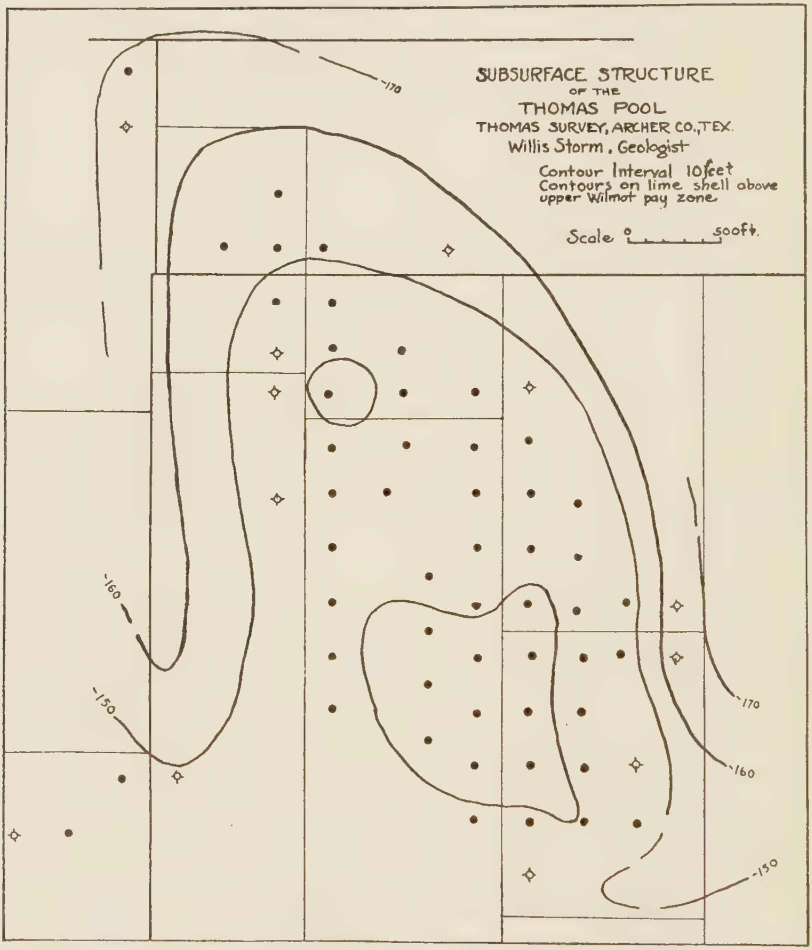


FIG. 4.—Subsurface structure of Thomas Pool, Thomas Survey, Archer County, Texas. (Courtesy of Willis Storm and Thornton Davis.)

Archer County and their relationship to each other. Subsurface folds are generally closely related in that several structures are along a single axis (Plate 1). The intensity of subsurface structures is partly due to sand thickness, since it is observed that edge wells in a field encounter little

or no sand or only sandy shale, and encounter the limestone cap lower, thus indicating the absent sand.

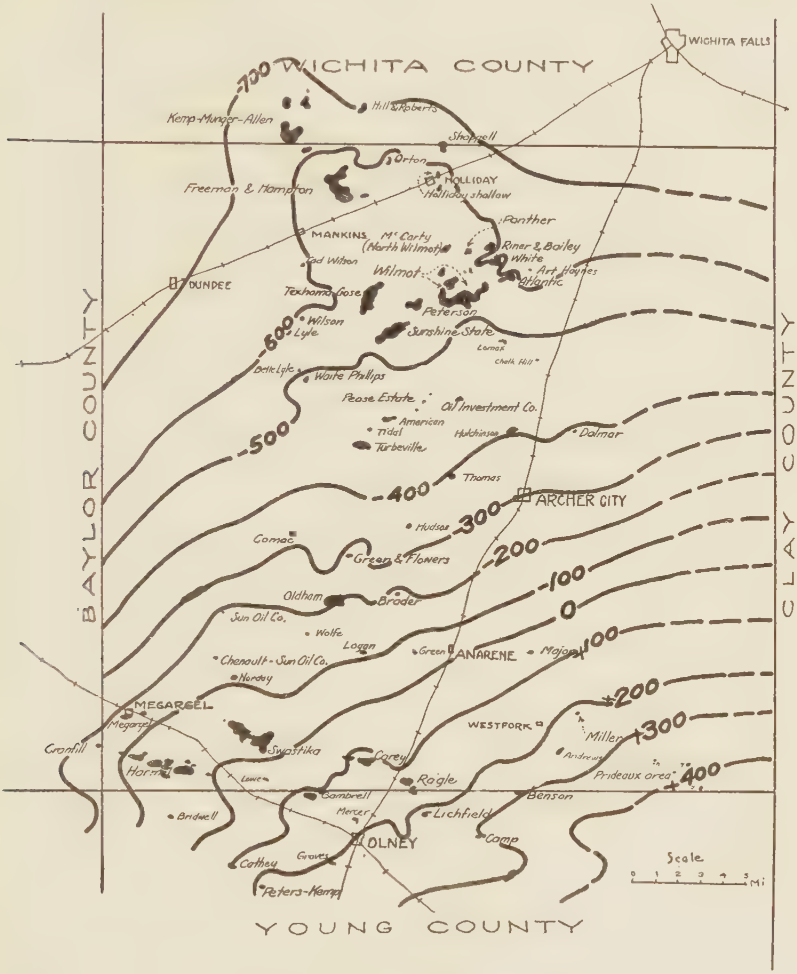


FIG. 5.—Index map of pools in Archer County, and generalized structure of the main pay sand. Sea-level datum.

As has been pointed out previously,[1] the origin of folds in Archer County is largely due to (1) settling (differential compacting), (2) deposition, and (3) folding incident to a compressive shortening of beds in

[1] Hubbard and Thompson, *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 5 (May, 1926), p. 474.

a subsiding area. In consideration of the small structures and prevailing low dip of the rocks in this area, an explanation based on some such cause is preferable to that of mountain-folding in areas relatively far removed.

The foregoing statements would also account for the formation of similar types of folds throughout Cisco and Wichita-Albany times, and, furthermore, would not require exact conformity between the lower and the surface beds.

ORIGIN OF OIL AND RESERVOIR

Ordinarily the presence of oil in lenticular sands or the occurrence of oil pools on small noses would be relatively easy to explain, but in Archer County we have a combination of the two conditions which makes an explanation much more complex. It is a known fact that all the pools in the county are on small but distinct folds whose axes extend in a general northwesterly direction. Some of these folds may be traced for several miles and may include several pools. The pools of the district are also in an approximately northeast-southwest alignment along the strike of Cisco rocks (Plate 1 and Fig. 5). The pools themselves are on terraces on these folds, and the size of each pool is governed by the size of a sand lens occupying this terrace (Fig. 6). The sand is very erratic, and a well in the middle of a pool may be dry on account of not finding sand; and furthermore one well may produce oil and one evidently still higher may produce water on account of the different wells encountering different lenses (Fig. 7). In general, however, the predominant sand body is structurally higher than the surrounding area, and only a few sands of considerable size are found in the low areas. Needless to say, the local structure in individual pools is due to some extent to this sand body, in other words, a detailed subsurface map of a pool shows the configuration of the top of the sand lens. The whole field, however, is higher than adjacent territory, thus showing that the sands were deposited on high areas.

The outcrop of the sand zone which has been correlated with the main Archer County "pay" exhibits the following definite conditions. Directly below the sand is a non-marine shale series showing a great amount of carbonaceous material in the form of plant impressions and coal, undoubtedly formed in a swampy area or tidal flat. The sand above this carries fossils which are unquestionably marine. From this it seems evident that at the time of deposition of the Gunsight sand zone the sea advanced over a low marsh or lagoonal area, depositing sand on the material which furnished the oil.[1]

[1] *Op. cit.*, p. 467.

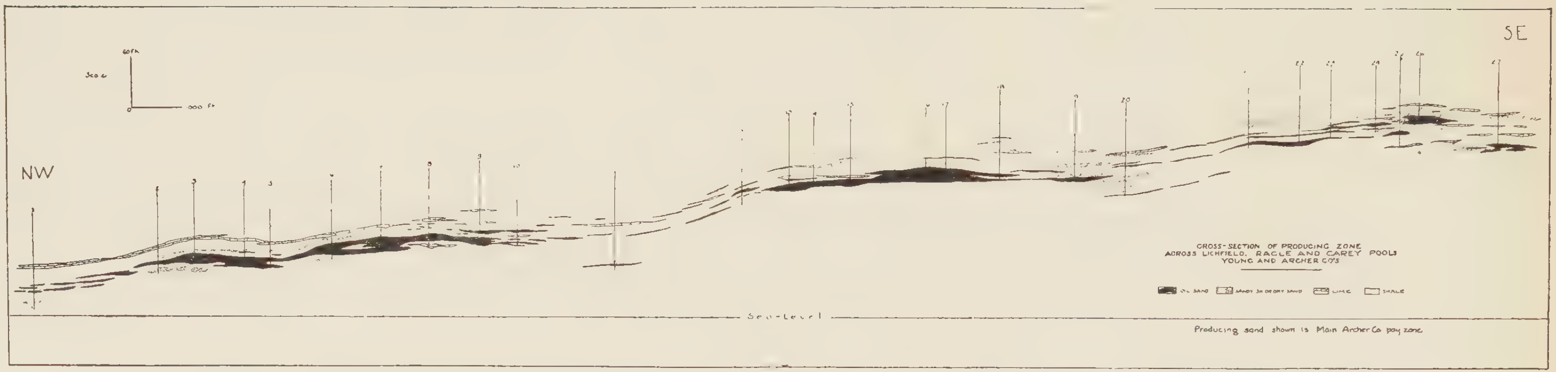


FIG. 6.—Detailed cross section of the producing zone in Litchfield, Ragle, and Carey pools, Archer and Young counties. Numbers refer to wells shown on map, Plate 1.

No evidence exists to show that there was any abnormal amount of heat developed in the formation of oil, at least from physical sources. There is practically no faulting in the rocks of the district and the folding is slight and probably caused by agencies that would produce little or no heat. The authors are of the opinion that the parent material for the present oil was formed by bio-chemical agencies in a swampy land area and that the oil went into the sand while the sand was being laid down, or soon afterward.

Such an explanation satisfies conditions as to relationship of source beds and sand and also accounts for the uniformity of physical and chemi-

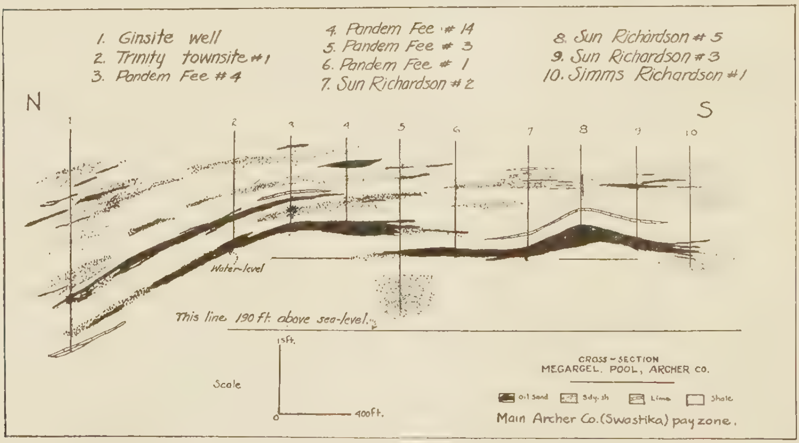


FIG. 7.—North-south cross section of the producing zone, Megargel field, Archer County.

cal characteristics of Archer County oil and its occurrence in particular horizons. All conditions indicate that the oil is indigenous to the relatively restricted zones from which it is produced.

Cisco sediments were laid down after a period of considerable folding in the mountain areas of southern Oklahoma and also in the mountains which existed along the present Red River area. Probably the pre-Cisco beds of north-central Texas were folded to some extent in a direction paralleling this movement. Subsequent folding caused by a shortening of beds as the area subsided would likely be continued, at least partly on these previously established lines of weakness. This being the case, the lower beds of the Cisco were probably laid down on a series of these low folds which projected into the advancing sea. Such a postulation is based on the fact that in several places in southern Oklahoma and north-

ern Texas, Pennsylvanian and Permian structural highs coincide with high topographic areas of that age.

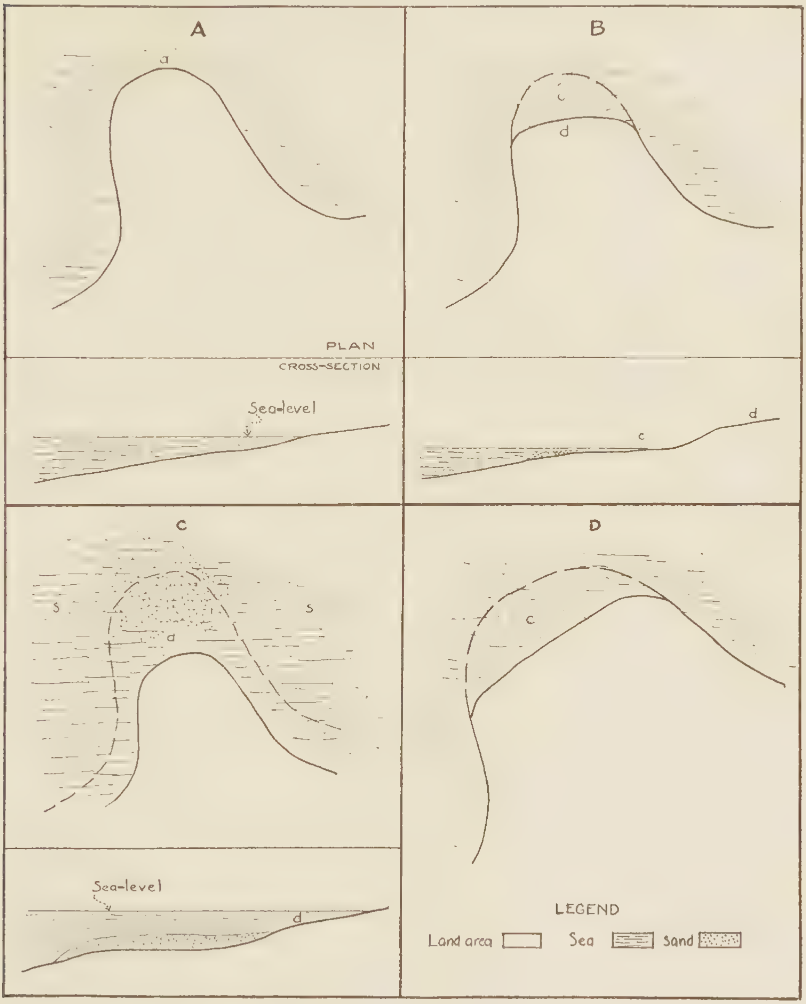


FIG. 8.—Diagrams and accompanying cross sections showing successive stages of sand deposition on high areas along subsiding coast line.

In Figure 8 let *A* represent this condition where one of these features, partly structural and partly topographic, extends into the sea. In a relatively shallow and somewhat limited sea, such as that which probably

existed in northern Texas at this time, there would not be the strong and complex shore currents that are found in larger and deeper oceans; consequently material would not be transported great distances. Naturally the greatest erosion would be at point *a*, and eventually the land features shown at *A* should be reduced to something similar to that shown at *B*. Most of the material eroded from area *c* would be deposited along the axis of this projecting feature, which would be shallower than surrounding areas. This might eventually form an offshore bar, but at any rate *c* would become an area alternately above and below tide-level, a tidal flat, or marsh.

When the sea advanced there would be a repetition of this process, and material eroded from *d* would be deposited at *c*. A good sorting of material would be expected, since the sand would be dropped first from the eroded material and the mud and silt which remain in suspension longer would be deposited in deeper water. This stage is shown at *C*. *S* shows relatively deeper areas where finer sediments would be deposited.

Such an explanation requires only two special conditions: (1) that there be alternate periods of advance and quiet in the sea, which could be reasonably postulated, and (2) that there be a relatively shallow restricted sea without strong currents, and this is also easy to visualize for Cisco time in northern Texas. There would undoubtedly be shore currents in some places, forming spits, hooks, and other shore features, and some such were evidently formed in the area under discussion. Practically every field in Archer County has some slight extension in direction and shape suggesting some of these features.

This explanation also accounts for the apparently different trend of some of the pools in northern Archer County. The long axes of some extend northeast instead of northwest, which is the general structural trend in the area. The folds on which pools with northeast axes occur are broader than others, and it is thought that the time interval between advances of the sea was not sufficient to permit the formation of a wide sand body from northwest to southeast. Naturally sand bodies on wide and narrow folds would take different shapes, even though the time interval for the formation of area *c* were about the same. Such a condition is shown at *D*. As has already been stated, the contours of any field reflect to a great extent the shape of the sand body, so that the fields of this type apparently would have northeast structural trends.

There is sufficient parallelism between several of the different pay zones to show that structural conditions which started in the lower Freeman-Hampton sand continued upward through at least the lower half

of the Cisco. Not all of the upper pay zones produce in as large an area as the lower zones, but production from the different sands coincides structurally to such an extent as to show that the lower structures persisted. This is less true with some of the shallower sands of Holliday district, but these are relatively unimportant.

It is to be expected that any folding due to subsidence would be likely to follow old lines of weakness. This would cause structures to be formed in younger rocks above the lower structures but less intense than those. Such a condition is observed to be true. Furthermore, with predominant deposition of sands on high areas and shales in the synclines, differential compacting would operate to make two sets of folds parallel.

In the erratic deposition of the more clastic beds of the upper Cisco and lower Wichita formations, these conditions would not hold true to such an extent as to make surface beds continue in conformity.

PRODUCTION DATA

Tables I and II give some idea of the relative importance of Archer County oil pools and the amount of oil produced. Table I shows the

TABLE I

Year	Production (in Barrels)	Year	Production (in Barrels)
1917	44,522	1922	848,370
1918	79,000	1923	5,261,596
1919	58,230	1924	11,185,732
1920	54,192	1925	13,579,331
1921	436,146	1926	11,602,733
		1927	9,648,832
		Total	52,798,684

amount of oil produced by years since the discovery of the first important pool in 1916. Table II gives a summary of all the pools, showing sand depths, productive area, and wells drilled.

Archer County oil is fairly uniform as to both physical and chemical properties, even though produced over a wide area and from different sands. The oil is ordinarily green, although some is brown or black. This latter condition is noticeable where the oil is produced with water. Gravity ranges from 37° to 41° Bé., generally depending on the life of the field. In almost all new fields the oil is 41° Bé. gravity. This figure declines as the sand is depleted and salt water encroaches. This oil will yield, on

TABLE II

ARCHER COUNTY OIL POOLS

Pool	Discovery Date	Acres	Producing Wells	Dry Holes	Sand Depths (Feet)	Sand*
American Refining.	7–23–26	145	54	8	1,480	1
Atlantic	5–10–24	200	41	12	1,550	1
Barkley-Meadows	11–17–23	120	13	4	1,570	1
Brader	6– 4–23	26	5	4	1,260	1
Burns & Maxson	5–13–25	60	15	7	1,415	1
Carey	10–11–24	268	100	27	1,100	1
Comac	4–20–24	65	13	6	1,460	1
Dalmar	5– 5–22	20	4	2	1,020	3
Freeman-Hampton.	8– 1–22	940	306	36	1,440–1,550–1,740	1, 2, 4
Green-Flowers	4– 5–25	48	8	4	1,400	1
Green (Anarene)	12–15–26	15	2	1	1,100	1
Harmel	9–11–24	731	188	46	1,300	1
Hudson	7– 1–26	80	20	5	1,140	2
Humphrie (White)	6–14–24	291	78	17	1,400–1,590	1, 2
Hutchinson	11–16–25	60	25	10	1,375	1
Ikert	2–12–25	40	15	4	1,270	1
Logan	7–21–26	30	7	0	1,125	1
Lyles, Belle Z.	2–24–27	50	28	3	1,525	1
Major	5– 3–24	40	13	3	1,020	1
McCarthy	5– 2–24	71	21	6	1,580	1, 5
Megargel Townsite.	10– 2–25	100	43	9	1,445	1
East Megargel	1– 1–26	35	13	7	1,420	1
Miller	10– 7–11	25	4	4	900	1
Muse-Robertson	5– 6–25	50	17	4	1,200	1
Norday	6–18–25	55	18	6	1,400	1
Oil Investment	11–22–24	80	23	6	1,105–1,205–1,415	3, 2, 1
Oldham	10–30–25	400	103	21	1,050–1,350	1–(3?)
Orton	4–16–24	81	17	5	1,430–1,590–1,800	1, 2, 4
Panther	8– 6–16	48	10	11	1,600	1
Pease	7–12–24	5	2	3	1,470	1
Peterson	3– 3–23	248	87	8	1,380–1,580	1, 2, 5
Prideaux	3– 5–25	†	68	14	600	1
Ragle	6–21–24	270	90	14	1,090	1
Riner-Bailey	1– 5–24	225	75	14	1,620	1, 2, 5
Shappell	2–13–23	185	29	6	1,800	4
Stampli-Roberts	11–20–24	250	78	29	1,350	1
Sunshine	5– 1–23	420	122	10	1,380–1,580	1, 2
Swastika	5–12–23	451	166	41	1,350	1
Texhoma-Gose	4–15–21	513	87	15	1,600	1
Thomas	5–26–26	90	43	10	1,165	2
Tidal-Farmer	9– 3–26	30	6	2	1,460	1
Turbeville	7–16–26	175	74	12	1,500	1
Waite Phillips	8– 5–24	75	25	7	1,500	1
Wilmot	6– 6–23	1,282	387	39	1,380–1,580	1, 2, 5
Wolfe	4–11–25	15	3	1	1,370	1
Tad Wilson (Howard)	4–18–25	40	7	4	1,700	4

* 1, Gose; 2, Upper Wilmot; 3, Dalmar; 4, Lower F-H; 5, 900-foot.

† Scattered wells in large area.

an average, 43 per cent gasoline, 8 per cent kerosene, 21 per cent gas oil, and 27 per cent fuel oil.

Water encroaches sooner or later in all fields, as a rule earlier than it should because wells are drilled too deep. Although the water is a serious problem, the quantity remains fairly constant after it appears, some leases showing a nearly constant water production through a long period of time.

Almost all drilling is done with the rotary system, and only one string of casing is used. The shallow depth, easy drilling, and high-gravity oil have made Archer County a profitable area for most operators.

Costs of wells are variable due to different factors, but an average well in northern Archer County can be completed ready to place on the pump for $10,000. In the shallower area in southern Archer County the cost is reduced by about $3,000.

Initial production varies from a few barrels up to more than a thousand. Several wells in the fields of southern Archer County produced as much as 1,200 barrels per day from sands 1,000 and 1,100 feet deep. These wells were exceptions, although wells with initial productions of 200 and 400 barrels are not uncommon in the early life of the important pools.

COPLEY OIL POOL OF WEST VIRGINIA[1]

DAVID B. REGER[2]
Morgantown, West Virginia

ABSTRACT

The Copley oil pool of Lewis and Gilmer counties, West Virginia, is an illustration of synclinal accumulation of oil in sands which carry no water. Oil occurs in the deepest part of the basin, at the foot of a descending axis, being almost surrounded by gas in the anticlines on either side and along the higher synclinal axis northeastward. Southwestward the pool is terminated by poor sand rather than by changed structural conditions.

Oil production began by the completion of the Copley gusher in 1900, and still continues with a prospect that the pool will have ten more years of life. Gas production on a large scale began about 1909 and still continues, although the rock pressure, which originally was 550 pounds, has declined to 65 pounds.

Production is mainly from the Gordon Stray, Gordon, and Fifth sands of the Catskill series of the Upper Devonian. There is little prospect of lateral extension of the pool, but there is hope of new gas production in deeper sands. Oil production is not probable in deeper sands unless it be found in the Lower Devonian and Silurian beds 7,000–10,000 feet deep.

INTRODUCTION

The Copley oil pool is one of the best illustrations of synclinal accumulation of oil in sands which carry no water. This type of occurrence, which is largely peculiar to the Appalachian fields of North America, is common in the Devonian sands of West Virginia, Pennsylvania, and southern New York, and not exceptional in the Mississippian sands of the same states and of the adjacent parts of Ohio and Kentucky, the region named being all within the drainage of the Appalachian geosyncline which passes from western New York southwestward to Alabama, with its deepest depression in Wetzel County, West Virginia (Fig. 1).

The Copley pool is located in Lewis and Gilmer counties, West Virginia, on Sand Fork of Little Kanawha River, near the village of Copley, which is approximately 13 miles southwest of Weston and about the same distance northeast of Glenville, and nearly on a straight line between these two county seats. It was briefly described in 1904 by White[3] in a general volume on oil and gas in West Virginia, but in 1914 it was visited

[1] Read before the Association by I. C. White at the Tulsa meeting, March 24, 1927. Reprinted from *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 6 (June, 1927), pp. 581–99.

[2] Assistant geologist, West Virginia Geological Survey.

[3] I. C. White, "Petroleum and Natural Gas," *West Virginia Geol. Survey*, Vol. 1A (1904), pp. 368–75.

by Reger,[4] who mapped the structure on the Pittsburgh coal and described the pool in more detail, giving numerous well records. Among the operators who contributed logs and data are the following: South Penn Oil

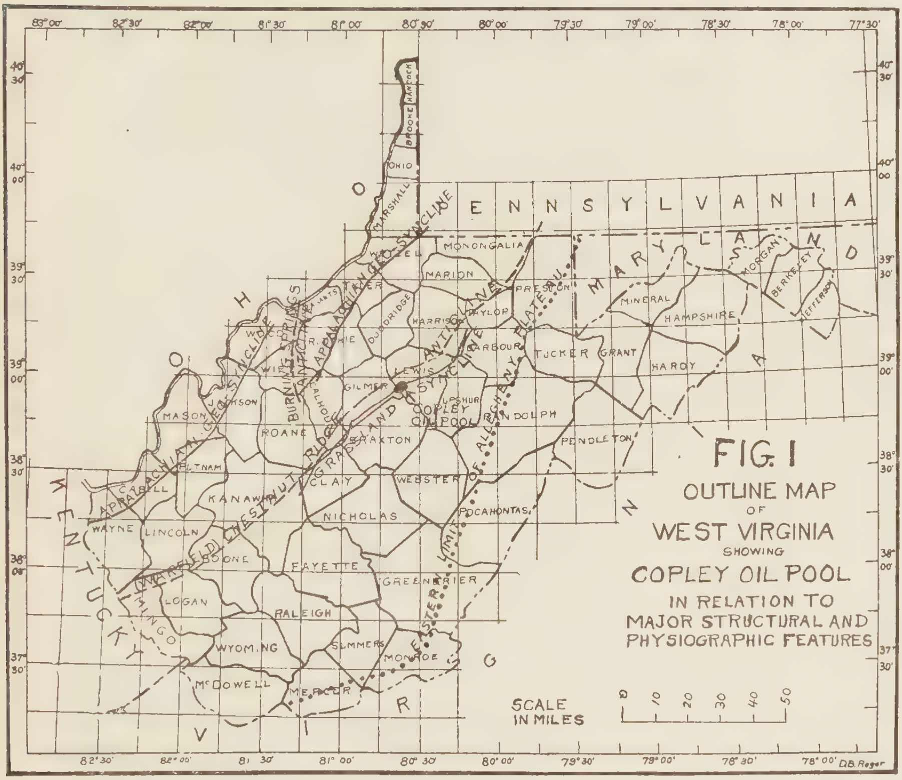


Fig. 1

Company, Hope Natural Gas Company, Pittsburgh & West Virginia Gas Company, Guffey & Galey, and United States Oil Company.

The present study is largely founded on the data of 1914, with the addition of subsurface and regional maps and production records and with a discussion of the scientific aspects of the pool. The report last cited should be consulted for the detailed well records of the pool.

[1] David B. Reger, "Lewis and Gilmer County Report," *West Virginia Geol. Survey* (1916), pp. 335–60.

PHYSIOGRAPHY

Considered in its relation to the major topographic features of the Appalachian Province, the Copley oil pool lies within the area of the Allegheny Plateau as defined by Abbe,[1] or within the Cumberland Plateau as used by the United States Geological Survey. This plateau embraces the central and western part of West Virginia, as shown by Figure 1, and in fact its outliers extend farther east in West Virginia and western Maryland. For the present discussion, however, it may be most easily visualized as ending at the limits shown on Figure 1, since the land east of this boundary, having been crumpled into mountain folds, is of the Allegheny Ridge type, and the territory westward as far as the Ohio and Mississippi valleys, being gently folded, offers little or no topography as a guide to the structure. This Allegheny Plateau, or sub-province, once a gently sloping plain, has been cut into innumerable ribbons by the drainage, which has left many sharp ridges. This plain is now somewhat raised along its eastern border where the elevation of the escarpment ranges from 2,500 to 4,000 feet above sea-level, but westward the plateau descends, steeply at first, and then more gently, until it is only about 1,400 feet at the Copley oil pool and 1,000 feet or less at Ohio River. As shown by Figure 2, the topographic relief at Copley ranges from 500 to 600 feet, and the valley of Sand Fork is about 800 feet above sea-level. There are only narrow bottoms along the larger streams, and there is no flat land of consequence on the ridges.

HISTORY

The Copley pool was opened September 13, 1900 with the completion of the Michael Copley Heirs well No. 1 by the South Penn Oil Company. According to local report the well has been drilled to the top of the Gordon Stray sand, which appeared to be so soft that a shut-down was ordered for the night; but before morning the well drilled itself in and began flowing wildly. There being no pipe lines available, earthen dams were built across Sand Fork, which fortunately, was almost empty of water on account of a protracted drought, and this expedient, in addition to a careful guard against fire, saved much of the oil until a line was laid.

The company record (Table II) indicates an initial production of 5,000 barrels a day, but this probably refers to flow that was gauged after the erection of tankage, since employees of the South Penn Oil Company and of the Eureka Pipe Line Company living at Copley, who

[1] Cleveland Abbe, Jr., "General Report on the Physiography of Maryland," *Maryland Weather Service* (1899), pp. 153 and 161–65.

FIG. 2. Topography of Copley oil pool, Lewis and Gilmer counties, West Virginia. Contour interval, 20 feet.

laid the line to the well, estimate the first production as 10,000 to 12,000 barrels.

Following the discovery well the pool was rapidly developed, with an area of six or eight square miles of oil in which 150 wells or more were drilled, and with a large gas production in the adjacent higher structure, the main financial interests concerned being those previously mentioned.

STRATIGRAPHY

COLUMNAR SECTION

Disregarding the slight deposits of recent Pleistocene material along the valleys, Table I illustrates the general nature of the rocks to such depths as drilling has gone.

EXPOSED BEDS

Of the formations described, the Dunkard series of the Permo-Carboniferous and about one-half of the Monongahela series of the Pennsylvanian are exposed in the Grassland syncline at Copley, but along the adjacent anticlines the full Monongahela and upper part of the Conemaugh are above drainage.

Dunkard series.—Of the Dunkard series, which has a maximum of about 1,200 feet along the Appalachian geosyncline farther west, there remains at Copley a thickness of only about 400 feet, this being the lower third of the series. These rocks consist of rather heavy gray or brown sandstones, some of which carry quartz pebbles, and beds of red or sandy shale with some thin and impure coals. In this part no limestones occur, and so far as known there are no marine fossils, but throughout the state the calcareous members of higher horizons carry a non-marine fauna of ostracods and other small forms. A few vertebrate tracks and some other slight remnants of Permian quadrupeds have also been found at scattered localities in other counties. The series was first correlated as Permian by Fontaine and White,[1] from the plentiful flora of northern West Virginia and southwestern Pennsylvania. No oil or gas production has been found in these rocks in West Virginia.

Monongahela series.—The Monongahela series lies just beneath the Dunkard and is the youngest formation of the Pennsylvanian. It consists of gray or brown micaceous sandstones, some of which are locally conglomeratic with quartz pebbles, red or sandy shales, coals, and impure limestones. Its base is formed by the great Pittsburgh coal, which is an

[1] William M. Fontaine and I. C. White, "The Permian or Upper Carboniferous Flora of West Virginia and Southwest Pennsylvania," *Pennsylvania Geol. Survey*, Vol. PP (1880).

TABLE I

General Columnar Section

Age	Period	Series	Description	Feet
Paleozoic	Permo-Carboniferous	Dunkard	Gray or brown micaceous sandstones with red or sandy shales and thin coal seams; apparently non-marine	400+
		Unconformity?		
	Pennsylvanian	Monongahela	Gray or brown micaceous sandstones with red or sandy shales, coals, and impure limestones; apparently non-marine; only partly exposed above surface	350–500
		Conemaugh	Gray or brown micaceous sandstones with red or sandy shales, thin coals, and impure limestones; two or three marine horizons; below drainage	500–650
		Allegheny	Gray, coarse sandstones, with gray or brown sandy shales and fire clays; apparently non-marine	150–250
		Pottsville	Gray, coarse, and conglomeratic sandstones, with gray or brown sandy shales and fire clays; only marine horizon known in Lewis County	300–600
		Unconformity		
	Mississippian	Mauch Chunk	Red and green shales with green, micaceous, flaggy and lenticular sandstones; lower part in these counties is probably marine	250–400
		Unconformity		
		Greenbrier	"Big lime" of well drillers; gray crystalline limestone with sandy streaks; plentifully marine	50–150
		Unconformity		
		Pocono	Gray or brown, coarse, and conglomeratic sandstones and gray or brown sandy shales; middle part is probably marine	200–450
		Unconformity		
	Devonian	Catskill	Red or green shale with red or brown cross-bedded sandstones which are lenticular; apparently non-marine	400–450
		Chemung	Green flaggy and fine-grained sandstones with much green sandy shale; highly marine; not drilled through in this region	?

important key rock in the oil fields of the state. Its exposed thickness at Copley is only about 175 feet, but its character is visible along the Chestnut Ridge anticline to the north and the Orlando anticline farther south, where its full thickness is 350 to 400 feet. In this region several of its coals are almost absent, but enough of the Pittsburgh remains for use as a correlation bed. No marine fossils have been observed, but many minute fresh-water ostracods and other types are found, and there is a coal flora which is partly Permian and partly Pennsylvanian in character. Dr. White frequently suggested that the Permo-Pennsylvanian boundary might be lowered into the Conemaugh series next below the Monongahela, because of the occurrence of Permian reptiles and other attendant phenomena in the Monongahela and Conemaugh rocks.

In the Monongahela series one oil sand, the Carroll (Uniontown sandstone), is known, being productive mainly in Ritchie County but being entirely above drainage in the Copley region.

SUBSURFACE BEDS

Conemaugh series.—The Conemaugh series, next beneath the Monongahela, is composed of gray or brown micaceous sandstones, some of which carry quartz pebbles, red or sandy shales, thin coals, and impure limestones. It has a thickness of 500–600 feet. The limestones and shales, as there are four horizons that are distinctly marine at exposures throughout the state, are good correlation zones at such localities; the coals also contains many plants of Pennsylvanian age. Although not exposed at Copley, the Conemaugh series is visible elsewhere in Lewis and Gilmer counties. As it exhibits little variation of character or thickness, its nature at Copley may be safely considered as much the same.

In descending order the Conemaugh contains five oil sands, as follows:

Minshall (Connellsville sandstone)
Murphy (Morgantown sandstone)
Moundsville (Saltsburg sandstone)
First Cow Run, or Little Dunkard (Buffalo sandstone)
Big Dunkard (Mahoning)

Of these five sands only the First Cow Run and Big Dunkard, so far as known, have made showings of oil or gas in Lewis and Gilmer counties, but these shows did not occur at Copley.

Allegheny series.—The Allegheny series, next beneath the Conemaugh, is distinguished by the absence of red shale, its principal beds being gray massive sandstones, many of which carry quartz pebbles, gray or brown sandy shales, and fire clays. Its thickness ranges from 150 to 250 feet.

Coals occur plentifully farther south in Lewis County, but are seemingly absent at Copley. The series is not known to be definitely marine in West Virginia, but in parts of Pennsylvania and Ohio there is a fossiliferous limestone in the lower part. Pennsylvanian plants are plentiful in regions where coals occur.

In descending order the Allegheny contains the following oil sands:

Burning Springs (Upper Freeport sandstone)
Gas sand (Lower Freeport sandstone)

No oil or gas, so far as known, has been found in these sands at Copley, but elsewhere in the two counties involved there have been showings of gas.

Pottsville series.—The Pottsville series is next below the Allegheny, and being the oldest formation of the Pennsylvanian, may be studied in the Lewis County panhandle 15 or 20 miles southeast of Copley, where it is composed of gray, coarse, and conglomeratic sandstones with white quartz pebbles, gray or brown sandy shales, and fire clays and coals. It has a thickness of about 600 feet. At Copley it is 500 feet or less in thickness, and its coals have largely disappeared. The series in this general region is only a remnant of the immensely developed series in southern West Virginia, where it is nearly 4,000 feet thick. In the panhandle of Lewis County it has only one known marine horizon, but its plant life is plentiful.

In descending order the Pottsville of this part of West Virginia contains several oil sands which have been imperfectly correlated but are generally listed as follows:

Gas sand of Marion and Monongalia counties, or Second
  Cow Run of Ohio (Homewood sandstone)
Gas sand of Cairo
Salt sand of Cairo
Cairo sand
Gas sand of Rosedale
Salt sand of Rosedale

Owing to deficient criteria for the correlation of these sands in regions where they are below the surface, they are by many called the "Salt sands" without further effort at distinction, and in this list there are probable duplications. Some of these sands produce oil and gas in nearby regions, but are not known to have made showings at Copley. The term "Salt sand" is applied to them because of their common content of salt water.

Mauch Chunk series.—Separated from the Pottsville by an unconformity of large proportions, the Mauch Chunk series of the Mississippian comes next in descending order. Locally this group consists of red and green shales and green, micaceous, flaggy, and lenticular sandstones, with a limestone near the base that is probably marine in character. Its thickness in the region ranges from 250 to 400 feet. This is but half the thickness exhibited at the nearest outcrop at Webster Springs, 35 miles southeastward, and as the series is known to differ widely in its physical and paleontological aspects from place to place, it may not be described with certainty at Copley. In southern West Virginia, as recently described by Reger,[1] the series is nearly 3,500 feet thick and contains many heavy quartzitic sandstones and marine limestones and shales, together with several coals. At Mauch Chunk and Pottsville, Pennsylvania, on the contrary, it appears to be strictly non-marine, although there are several species of vertebrate tracks, and it is almost wholly composed of red mudstones, with only a few quartzitic beds. In regions like Copley, where it is deeply buried and where it represents only a decadent phase, its members cannot be definitely correlated.

One oil sand, the Maxton (Droop sandstone?), is generally recognized in the Mauch Chunk by the drillers, but it remains to be established that the same horizon is so called in different localities. Another formation, the "Little lime" (Reynolds limestone), near the base of the series, has in places produced a little oil. Neither of these beds has been found valuable at Copley.

Greenbrier series.—The Greenbrier series, next under the Mauch Chunk, from which it is separated by an unconformity of minor rank, is locally composed of 50 to 150 feet of gray and probably crystalline limestone that is most certainly of marine origin, since its character is such at nearly all outcrops except at some localities north of the West Virginia-Pennsylvania state line. There is ample reason for belief that this remnant of a series that is 1,800 feet thick in southern West Virginia and even thicker in southwestern Virginia is mainly, if not entirely, the Union limestone member, which in turn is a most probable equivalent of the Maxville of Ohio and of the combined Gasper and Fredonia of more western states. This formation is known as the "Big lime" by the drillers, and is a correlation bed of great value. Although productive of much gas in southern counties, where it is more sandy, it has afforded no oil or gas at Copley.

[1] David B. Reger, "Mercer, Monroe, and Summers Counties," *West Virginia Geol. Survey* (1926), pp. 291–444.

Pocono series.—The Pocono series, just below the Greenbrier, from which it is separated by an unconformity due to the local absence of at least 2,500 feet of sediments, is a group of clastic rocks composed of gray or brown, coarse, and pebbly sandstones, and gray or brown sandy shales. It has a thickness of 200 to 450 feet. For many years this series has been considered as essentially non-marine, with only rare occurrences of fossils. In recent years, however, a more intensive study has revealed the presence of many marine fossils in the upper part of the lower half of the series, as recently stated by Reger,[1] and as also noted by Charles Butts,[2] of the U. S. Geological Survey. Probably the best correlation plane for subsurface identification in this series is the Sunbury shale, known to the drillers as the Coffee shale on account of its brown or black color. It is located just above the Berea sand. At its type locality in Ohio, as well as at outcrops in southern West Virginia, this shale contains *Lingula melie* and *Orbiculoidea* (*Linguladiscina*) *herzeri;* and these should presumably occur in deep wells across the Appalachian geosyncline. In surface outcrops, however, the more plentiful and larger fossils of the Broad Ford sandstone, just above the Sunbury shale, are more easily recognized, a species of *Syringothyris* being common.

In descending order the oil sands of the Pocono are as follows:

Keener sand and Beckett sand of Milton
Big Injun sand (Logan sandstone)
Squaw sand
Weir sand (Broad Ford sandstone)
Berea sand

These Pocono sands have produced no oil and not much gas in valuable quantity in the Copley pool, although some of them are richly productive under similar structural conditions elsewhere in the state.

Catskill series.—The Catskill series, next below the Pocono, is the youngest formation of the Devonian in the Appalachian region. It is composed of clastic beds, among which red and green shales form the larger part, with red or greenish-brown, cross-bedded, lenticular sandstones. Its local thickness ranges from 400 to 500 feet. Generally considered as lacking in both marine and plant remains and as otherwise lacking readily distinguishable material, its outcrops have never received deserved attention. Recent studies by the writer,[3] however, have shown a

[1] *Op. cit.*, pp. 503–32.

[2] Personal conferences.

[3] David B. Reger, "Pocono Stratigraphy of the Broadtop Basin of Pennsylvania," *Geol. Soc. Amer.*, Madison meeting, December, 1926.

constant plant horizon (Saxton shale), which is a good correlation zone, near the top of the series and extending over a wide belt of Pennsylvania and West Virginia. This horizon also carries a pelecypod fauna in Randolph County.

In descending order the Catskill contains the following oil and gas sands:

Gantz sand
Fifty-foot sand
Thirty-foot sand
Gordon Stray sand
Gordan sand
Fourth sand
McDonald or Fifth sand
Bayard or Sixth sand
Elizabeth or Seventh sand

These sands comprise the well-known Venango group of Pennsylvania. Their correlation southward into West Virginia has been attempted almost solely by interval from well to well with the help of the superjacent and subjacent formations which are fairly certain. Owing to the lenticular nature of these sands, their recognition at most localities is doubtful at best, especially when additional sands appear, as they do in many places.

In the Copley pool the so-called Gordon Stray, Gordon, and Fifth sands have been the oil-producing horizons, the Gordon being the most prolific. The same sands have generally produced gas in the rising structure away from the Grassland syncline.

Chemung series.—The Chemung series, next below the Catskill, a highly marine group of thin flagstones and shales generally olive-green in color, has seldom been reached by the drill at Copley. Elsewhere in the state some of its beds produce gas, but its further discussion is not herein appropriate.

LOG OF TYPICAL WELL

Figure 3 is a detailed graph of the record of the J. W. Cox well No. 1 (West Virginia Geological Survey No. 397), drilled by Guffey and Galey and located on Rock Run 0.6 mile north of Bealls Mills in the Copley oil pool. The drilling of this well commenced on a hillside below the base of the Permian, but penetrated nearly to the base of the Catskill and showed both the Pittsburgh coal and nearly all the oil sands, reaching production in the top of the Fifth sand.

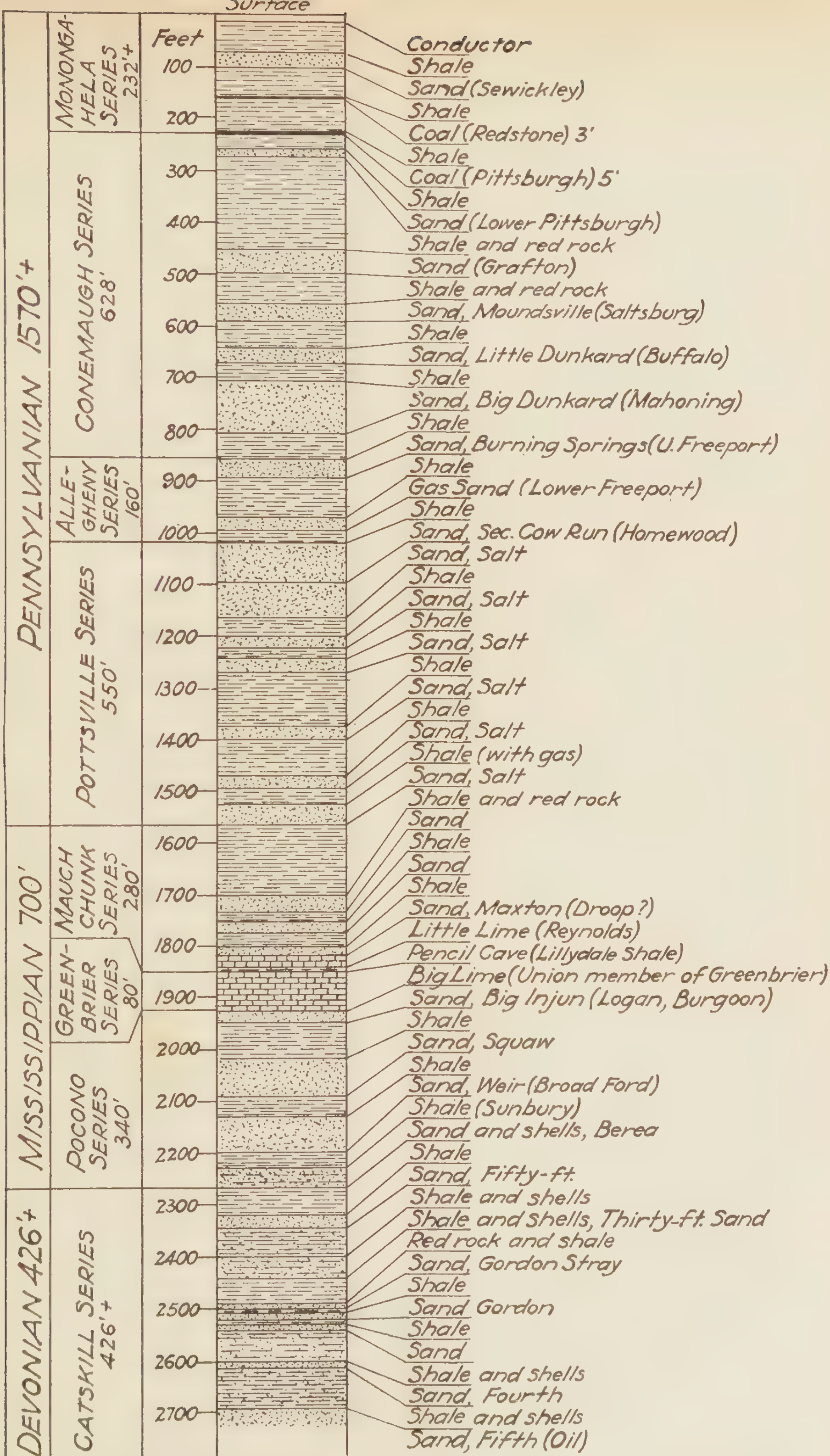


FIG. 3.—Log of typical well, J. W. Cox No. 1 (397), by Guffey & Galey, on Rock Run, 0.6 mile north of Bealls Mills, Copley oil pool, Lewis and Gilmer counties, West Virginia.

CONDITIONS OF DEPOSITION

Disregarding the Permian and Pennsylvanian sediments, which were mainly formed in bogs subject to periodic depression, the Mississippian and Devonian rocks were mostly accumulated in the shallow Appalachian sea, the source of the clastic material being old ranges of granitic or quartzitic rock which once existed near the present Atlantic seaboard and east of the present Appalachian Mountains. In all of the major groups, with the possible exception of the Greenbrier, there were stages of emergence during which land plants could grow. In the Mauch Chunk and Catskill also there is evidence of extensive oxidation, but it is by no means certain that all this oxidation took place when sedimentation was in progress. Much of it may have occurred in previous loci of the material, the red color being retained through any successive migrations.

COMPETENCY OF BEDS

With the possible exception of the Mauch Chunk and Catskill, which are of weaker material, the sediments occurring at Copley contain many heavy sandstones capable of offering much resistance to the thrust forces from ancient Appalachia farther east, this being especially true of the vast mantle of Permian and Pennsylvanian, 2,000 feet or more in thickness, which generally covers the Appalachian geosyncline. It is very well known that several thousand feet of incompetent Devonian shales occur beneath the Catskill, but there is no evidence for belief that these have extensively buckled beneath the protective upper beds in regions so far removed from the mountains as Copley.

SURFACE STRUCTURE

REGIONAL FOLDS

Figure 1 indicates the position of the Appalachian geosyncline which enters West Virginia at the southwestern corner of Pennsylvania and passes entirely across the state, entering Kentucky 10 miles or so south of its common corner with West Virginia and Ohio, but being interrupted, or staggered, by the Burning Springs anticline, which crosses it obliquely in Wood and Wirt counties. Farther east the Chestnut Ridge (Warfield) anticline makes a rather bold uplift across the state. Southeast of this anticline only a few major oil pools, of which Copley is one, have been found.

In the region between the Chestnut Ridge anticline and the eastern limit of the Allegheny Plateau there are several small folds, of which the Grassland syncline, holding the Copley pool, is an example. These minor folds are generally of comparatively short extent.

DETAILED STRUCTURE ON PITTSBURGH COAL

As shown by Figure 4, the surface structure drawn on the Pittsburgh coal, which is beneath drainage at Copley but which crops out in adjacent anticlines, is that of an almost symmetrical syncline rising toward the Chestnut Ridge anticline, $3\frac{1}{2}$ miles farther northwestward, at the rate of 100 feet per mile, and toward the Orlando anticline, 6 miles southeastward, at the rate of 75 feet per mile. The axis of this Grassland syncline also rises northeastward at the rate of nearly 40 feet per mile in the first 6 miles from Copley, and this rise continues somewhat more gently for 13 miles, or 19 miles in all, from Copley, the average rate for the 19 miles being 30 feet per mile. Southwest of Copley the axis is nearly flat for 8 miles, after which an extensive rise begins. In the region of Copley the floor of the basin is nearly 1 mile wide, and this width increases southwestward until at some points it is nearly 2 miles wide.

SUBSURFACE STRUCTURE

CONTOURS ON GORDON OIL SAND

Figure 5 shows the subsurface structure on the top of the Gordon oil sand in terms of feet *below* sea-level.

COMPARISON WITH PITTSBURGH COAL CONTOURS

The Gordon contours show a less symmetrical relationship toward the adjacent anticlines, the axis of the basin being farther northwest and the rise toward the Chestnut Ridge anticline being correspondingly steepened while the southeastward rise is perceptibly flattened. Also the floor of the basin is much narrower, and there are two depressions, one northeast and one southwest of Copley, which do not show in the Pittsburgh coal. These features indicate a slightly greater tendency toward buckling than occurs in the surface beds.

ABSENCE OF FAULTS

Like nearly all other West Virginia oil fields, the Copley pool structure is complicated by no faults of any kind. In the developed oil and gas pools of the state the only known fault is one which crosses Mingo County immediately southeast of the Chestnut Ridge (Warfield) anticline.

RESERVOIR ROCKS

LITHOLOGY

Following a careless custom established by 40 years of drilling prior to the year 1900, the records of the Copley pool furnish regrettably few descriptive adjectives regarding the sands and other formations, and there

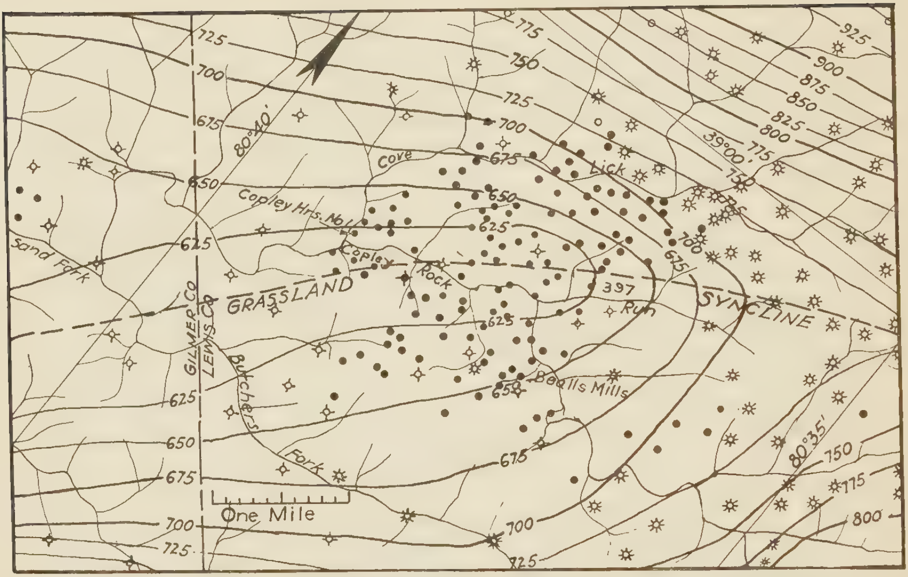


Fig. 4.—Surface structure, Copley oil pool, Lewis and Gilmer counties, West Virginia. Contours show elevations of Pittsburgh coal *above* sea-level, in feet.

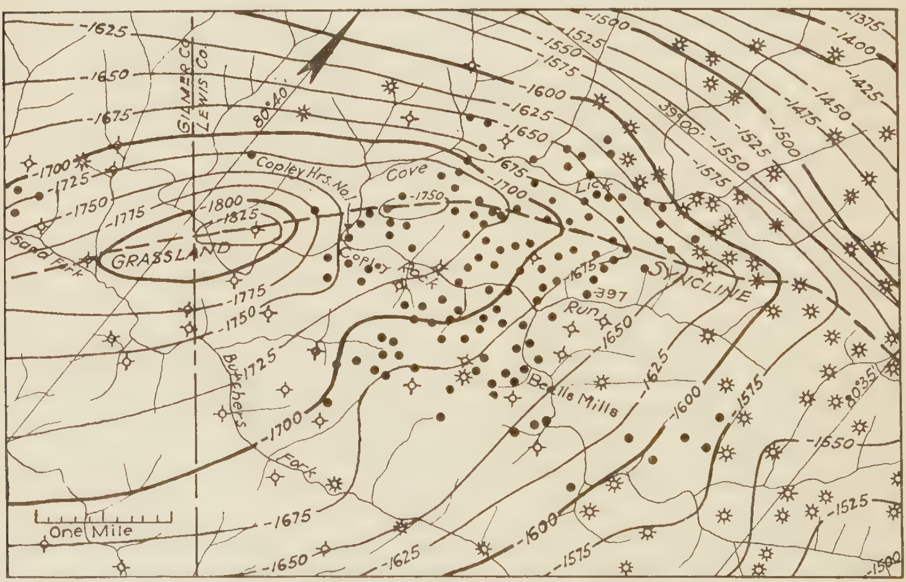


Fig. 5.—Subsurface structure, Copley oil pool, Lewis and Gilmer counties, West Virginia. Contours show elevations of top of Gordon oil sand *below* sea-level, in feet.

are no petrographic studies of these sands in this or any neighboring region known to the writer. The nearest outcrop of the Catskill series is in Rich Mountain, 35 miles eastward, where, along the Staunton and Parkersburg pike, as measured by Reger, it has a thickness of 470 feet, or much the same as at Copley, but where there is probably a greater proportion of sandstone, since the locality borders on a region where rapid thickening occurs. As noticed at this exposure, the sandstones of the lower half, in which the Copley production appears to belong, are generally green or greenish-brown, medium-coarse, cross-bedded, and only moderately hard, there being many streaks of shale, some of which are oblique to the general bedding planes. Quartz pebbles are almost, if not totally, absent. This is the common nature of the Catskill sands that outcrop along the westernmost Allegeheny ridges, except that in some regions they are reddish-brown instead of green.

CONTINUITY AND POROSITY

Thicknesses of the Gordon Stray, Gordon, and Fifth sands in the Copley region range from 5 to 25 feet, as a rule, and since they are of a lenticular nature, the absence of one or more of the three in any given well is not uncommon. Along the Grassland syncline, southwest of Copley for 2 or 3 miles, most of the drilling resulted in failure, evidently due to the absence of sands or to a shaly or non-porous character. Farther on, in Gilmer County, 3 or 4 miles beyond Copley, a belt of productive Fifth sand was found at the mouth of Indian Fork, but apparently the Gordon was worthless.

No tests on porosity of the productive sands of the Copley pool are available, so far as known, either at this or any other locality in West Virginia.

ORIGIN

The Catskill sediments, in which the productive sands at Copley belong are generally considered as highly oxidized, indicating long exposure to the air. It is not evident, however, that all this exposure took place during the present cycle of deposition. It is possible that oxidation may have been far advanced in the eastern highlands of Appalachia before degradation began, and that the transportation of sand and silt from these highlands westward to the Appalachian sea may have been slow, with frequent intervals of lodgment along the way. Such a condition is suggested by the highly comminuted nature of the material and by the broken and fragmentary character of such plant fossils as now remain.

SOURCE ROCKS

The scarcity of organic matter, both of vegetable and animal origin, and the oxidized character of the sediments in the Catskill series are so pronounced as to cast much doubt on the idea that any large amount of oil may have originated in these beds. On the other hand, the different groups of the Upper Devonian farther down, including the Chemung, Portage, Genesee, Hamilton, and Marcellus, are generally plentifully marine, and some of these groups are even noticeably bituminous in character, although they contain few porous horizons capable of holding large quantities of oil. The Chemung and Portage also sustained rather luxuriant vegetation, as is evident in the Tygart Valley of Randolph County, where Reger has recently measured trees that range from 1 to 4 feet in diameter, as will be discussed in a forthcoming publication. It is easy to believe that oil and gas could have originated in these lower shales, being gradually pushed upward into the more porous Catskill by increasing superincumbent weight.

RELATION OF ACCUMULATION TO STRUCTURE

REGIONAL

As in many other major petroliferous provinces of the world, the oil of the Appalachian region occurs in the minor structures of a vast geosyncline where there was a long era during which the accumulation and preservation of organic matter were scarcely interrupted.

LOCAL

Locally, the oil of the Copley pool occurs in a comparatively deep syncline in sands which carry no connate water. It is worthy of note that gas is found not only in the anticlines on either side but also along the axis of the syncline for many miles after it begins its rather constant rise 2 miles northeast of Copley. Such instances of accumulation are common in the non-hydrous sands of the Appalachian fields, and illustrate the anticlinal, or gravity, theory of the oil and gas accumulation as advanced by White[1] many years ago.

MIGRATION

There is little evidence for belief that the oil at Copley has traveled far in any lateral direction, since on the west it is cut off from the main Appalachian geosyncline by the Chestnut Ridge anticline, and on the

[1] I. C. White, "The Geology of Natural Gas," *Science*, June 26, 1885; republished in "Oil and Gas," *West Virginia Geol. Survey*, Vol. 1A (1904), pp. 49–52.

east by the Orlando anticline and by outcrops farther on. It is rather to be believed that upward migration from the deeper Devonian shales was the main movement, and that the oil found lodgment in the low part of the synclinal basin, while the gas continued laterally toward the adjacent anticlines and toward the higher structure of the syncline northeastward.

OIL

PHYSICAL AND CHEMICAL CHARACTER

Owing to the fact that the sand oils of West Virginia show little variation in physical and chemical character from pool to pool, being all of paraffin base and practically free from sulphur, and being usually turned into trunk pipe lines without attempt at segregation, numerous pools of considerable size have delivered their production for many years without published analyses of the oil. This appears to have been the case at Copley, where no analyses are available. In the Alvy pool of Tyler County, however, 30 miles or more farther north, Day[1] gives an analysis of Gordon sand oil that probably approximates the nature of the Copley pool. This sample was collected by M. J. Munn from the J. F. Ingraham lot well No. 1 at a depth of 2,670 feet, with analysis as follows:

ANALYSIS OF OIL FROM ALVY POOL, TYLER COUNTY

Physical properties:		
Specific gravity at 60° F.		0.8078
Baumé gravity at 60° F.		43.3
Color		Medium amber
Odor		Like Pa. oil
Distillation by Engler's method:		
Begins to boil at		70° C.
	Cubic Centimeters	Specific Gravity
By Volume:		
To 150° C.	14.0	0.7163
150°–300° C.	38.0	0.7840
Residuum	46.7	0.8621
Total	98.7	
		Percentage
Sulphur		....
Paraffin		6.11
Aslphalt		0.00
Unsaturated hydrocarbons, crude		7.6
Unsaturated hydrocarbons, 150°–300° C.		4.0

[1] David T. Day, "Mineral Resources," *U. S. Geol. Survey*, Part II (1909), pp. 424–25.

The analysis of this oil in Tyler County compares favorably with nearly all other sand oils in West Virginia and is probably fairly representative of the Gordon and other Catskill series oils at Copley.

OIL PRODUCTION

Figures on oil production are not available for the entire pool, since various operations are involved, some of which are now abandoned. C. B. Turner, general manager of the South Penn Oil Company, however, has very kindly furnished the complete production record of the Michael Copley Heirs lease, as herewith reproduced in Table II.

It is evident from Table II that the lease has produced 1,978 barrels of oil per acre, and computing the ultimate gross production as 281,714 barrels on the basis of the estimate furnished, the ultimate total per acre will be 2,201 barrels.

TABLE II

PRODUCTION RECORD OF MICHAEL COPLEY HEIRS 128-ACRE LEASE, AS FURNISHED BY SOUTH PENN OIL COMPANY

A. DEPTH AND INITIAL PRODUCTION OF EIGHT WELLS

Well No.		Depth (in Feet)	Sand	Initial Production First 24 Hrs.
1	Completed 9/13/1900	2,530	Stray	5,000 bbls.
2	Completed 12/ 6/1900	2,671	Gordon	20 bbls.
3	Completed 1/18/1901	2,625	Gordon	600 bbls.
4	Not Drilled	....	....	....
5	Completed 5/27/1901	2,880	Fifth	Dry and Abandoned
6	Completed 9/22/1919	2,688	Gordon	2 bbls.
7	Completed 9/ 2/1920	2,970	Gordon	15 bbls.
8	Completed 12/20/1920	3,100	Fifth	Dry and Abandoned

B. LOG OF WELL NO. 1

Log of Well No. 1	Depth (in Feet)
Pittsburgh coal	140
Pencil Cave	1,775–1,800
Big lime	1,800–1,895
Big Injun	1,895–2,025
Stray	2,512–2,524
Oil	2,519
Gordon	2,530
Total depth	2,530

C. PRODUCTION*

Well No.	Year	Production (7/8)	Royalty (1/8)	Total Production	Daily Average Production for Lease	Daily Average Production per Well
		Bbls.	Bbls.	Bbls.	Bbls.	Bbls.
1-2	1900	153,103.43	21,871.92	174,975.35	1,590.69	795.34
1-2-3	1901	27,072.74	3,867.53	30,940.27	84.77	28.26
1-2-3	1902	3,498.27	499.75	3,998.02	10.95	3.65
1-2-3	1903	1,913.84	273.41	2,187.25	5.99	2.00
1-2-3	1904	1,018.94	145.56	1,164.50	3.19	1.06
1-2-3	1905	2,290.54	327.22	2,617.76	7.17	2.39
1-2-3	1906	2,523.14	360.45	2,883.59	7.90	2.63
1-2-3	1907	1,970.09	281.44	2,251.53	6.17	2.06
1-2-3	1908	2,271.05	324.44	2,595.49	7.11	2.37
1-2-3	1909	1,183.17	169.02	1,352.19	3.70	1.23
1-2-3	1910	1,228.32	175.47	1,403.79	3.85	1.28
1-2-3	1911	1,116.66	159.52	1,276.18	3.50	1.17
1-2-3	1912	1,024.41	146.34	1,170.75	3.21	1.07
1-2-3	1913	1,174.47	167.78	1,342.25	3.68	1.23
1-2-3	1914	1,153.48	164.78	1,318.26	3.61	1.20
1-2-3	1915	1,070.20	152.89	1,223.09	3.35	1.12
1-2-3	1916	1,272.46	181.78	1,454.24	3.98	1.33
1-2-3	1917	1,360.59	194.37	1,554.96	4.26	1.42
1-2-3	1918	1,761.77	251.68	2,013.45	5.52	1.84
1-2-3-6	1919	1,741.59	248.80	1,990.39	5.45	1.36
1-2-3-6-7	1920	2,867.65	409.66	3,277.31	8.98	2.24
1-2-3-6-7	1921	2,058.00	294.00	2,352.00	6.44	1.61
1-2-3-6-7	1922	1,680.40	240.06	1,920.46	5.26	1.31
1-2-3-6-7	1923	1,551.29	221.61	1,772.90	4.86	1.21
1-2-3-6-7	1924	1,466.95	209.56	1,676.51	4.59	1.15
1-2-3-6-7	1925	1,491.09	213.01	1,704.10	4.67	.93
1-2-3-6-7	1926	1,597.56	228.22	1,825.78	5.00	1.00
Totals	....	222,462.10	31,780.30	254,242.40	26.48	....

* Estimated recoverable for 7/8 or working interest, 246,500 bbls.

GAS

VOLUME AND PRESSURE

The gas which occurs in large volume on the rising structure northwest, northeast, and southeast of the Copley pool was not exploited to any large extent during the flush years of the pool, but in later years has been intensively produced. Under date of February 7, 1927, John B. Corrin, vice-president and general manager of the Hope Natural Gas Company, discusses it in the following letter:

I have your letter of January 31, asking for certain data in connection with the Copley oil pool in Lewis and Gilmer counties, West Virginia. To give you the information requested in detail would require considerable work on the part of our office force, which we are not able to do at this time. However, I wish to state in a general way that the majority of the gas wells situated in the area east of the Copley field were drilled in the years 1909 to 1917. The principal

production is from the Gordon Stray and Gordon sands, with an occasional Injun sand well. The average original open flow of the Gordon Stray sand and Gordon sand wells was 1,500,000 cu. ft., with an average rock pressure of 550 pounds. The average rock pressure of the field has declined until today it averages 65 pounds. We have no data available as to the present open flow, nor the daily production of the field.

Like many other oil and gas fields of the state, the production of the Copley pool is largely merged with that of others which pass through the same pipe lines. In the case of gas especially, the saturated strata are continuous with other localities, and hence segregation of production figures would hardly be possible even if full records had been kept.

ABSENCE OF WATER

Like nearly all other pools in which the sands of the Catskill series have been productive in West Virginia and southwestern Pennsylvania, no water is found in the syncline at Copley. In the case of a pool like Copley, where the sands are mostly saturated with oil and gas, this absence of water, although anomalous as compared with many other regions, may be explained as due to displacement, but in localities where there is neither oil nor gas, the content of such pore space as must exist in these barren sands has not been explained to the satisfaction of all. Reeves[1] has suggested that this pore space has been dried out and later occupied by air, but Shaw[2] disputes this idea with the statement that if air existed in the sands, it would be under heavy pressure and would find an outlet when wells were drilled. He suggests further that some water may still remain in the sands; and it would appear to the writer that a more logical explanation would be that a small quantity of water is actually present in these sands, being barely enough to form a seal against the entry of air at outcrops, but insufficient to flow through the sand into a drill hole and insufficient to resist or greatly impede a flow of oil accompanied by gas pressure.

DRILLING AND PRODUCTION METHODS

All drilling in the Copley pool has been done with cable tools and standard 84-foot wood or steel derricks, power being furnished mainly by steam boilers fired by natural gas. For pumping, a central boiler plant is usually placed for each five or six wells, with an engine at each derrick. This method, however, is gradually being displaced throughout West Vir-

[1] Frank Reeves, "The Absence of Water in Certain Sandstones of the Appalachian Oil Fields," *Econ. Geol.*, Vol. 12 (1917), pp. 354–78.

[2] E. W. Shaw, *Econ. Geol.*, Vol. 12 (1917), pp. 610–28.

ginia by gas engines located at each well. Owing to the necessity of re-shooting and cleaning out, the derricks are left at all oil wells, but are generally removed from gas wells after the final cleaning-out.

LIFE OF WELLS AND POOL

It is evident from Table II that three wells on the Copley lease, including the discovery well, have pumped more than 25 years; and judged from the fact that a future estimated gross recovery of more than 27,000 barrels is still anticipated from the lease, probably by additional shooting and cleaning-out, a future life of perhaps 10 years may be expected. Other properties in the same pool, many of which are still producing, were drilled immediately after the Copley gusher, and hence it would appear that an ultimate life of about 35 years for these sands of the Catskill series may be the rule.

FUTURE DEVELOPMENT

A revival of this old pool through lateral extensions of territory is not probable, since many tests have been drilled in the adjacent parts of the syncline. Scattered wells may be found, but large productive areas may not be expected. Deeper drilling may find additional gas in the sands of the Chemung series along the anticlines and the eastern extension of the syncline, but these lower sands have never produced much oil in West Virginia. It is of course true that the Oriskany sand of the Lower Devonian, and the "Clinton" (White Medina) sand of the Silurian, may be present beneath the Copley pool and may hold oil, but wells must be drilled 7,000 to 10,000 feet deep to reach them, so that their exploration is probably remote.

CABIN CREEK FIELD, WEST VIRGINIA[1]

THERON WASSON AND ISABEL B. WASSON[2]
Chicago, Illinois

ABSTRACT

The Cabin Creek field is located in central West Virginia, 20 miles southeast of Charleston, on the Allegheny Plateau. It is owned and operated almost entirely by The Pure Oil Company, and is, therefore, an excellent example of unit operation. The pool is strictly a monoclinal accumulation close to the axis of a syncline. Production comes from the thickened lensed portion of the lower part of the Berea sand found at depths from 2,700 to 3,200 feet. The lens extends parallel with the synclinal axis, over an area 12 miles long by $\frac{1}{2}$ mile wide. There is no water in the Berea sand, and, therefore, the accumulation is by gravity, the oil occupying the lens as far down the slope as the pay lens exists, with gas extending up the slope about one mile northwest of the oil field. The field has been developed since 1914 to the extent of 300 wells, but the known producing area is only a little more than half drilled. The average gravity of the oil is 47° Bé., and is remarkable for its lubricating quality.

INTRODUCTION

Since this is the first report ever published on the geology of the Cabin Creek pool, West Virginia, an attempt has been made to present a fairly complete account of the field.

The Cabin Creek field is located in south-central West Virginia, about 20 miles southeast of Charleston. The oil always brings a better price than Pennsylvania grade, due to its excellent lubricating quality, and its high gravity, which averages 47°. Practically the entire pool is owned and operated by one company, The Pure Oil Company. Therefore, the development has been steady for the last 10 years. New wells are drilled to maintain a constant production. The production records are probably more complete than those of any other pool in the country. Each well has its own receiving tank so that the production has been kept for each well, each day, since the first well was drilled in December, 1914. The oil is run by gravity lines to the Cabin Creek refinery, also owned by The Pure Oil Company, 4 miles north of the field. Drilling and lifting costs are low as compared with the Mid-Continent fields. Ultimate production per acre is high compared with other eastern pools.

[1] Read before the Association at the Tulsa meeting, March 25, 1927. Reprinted from *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 7 (July, 1927), pp. 705–19.

[2] The Pure Oil Company, 35 East Wacker Drive.

REGIONAL STRUCTURAL LOCATION

The Cabin Creek field trends northeast and southwest, parallel with the major structural axes of the state, as will be noticed on the map of West Virginia (Fig. 1). The pool is 12 miles long and ranges from ½ to 1 mile wide.

All other pools in West Virginia lie northwest of the Coalburg syncline, and its extension northeastward. This structure divides the state

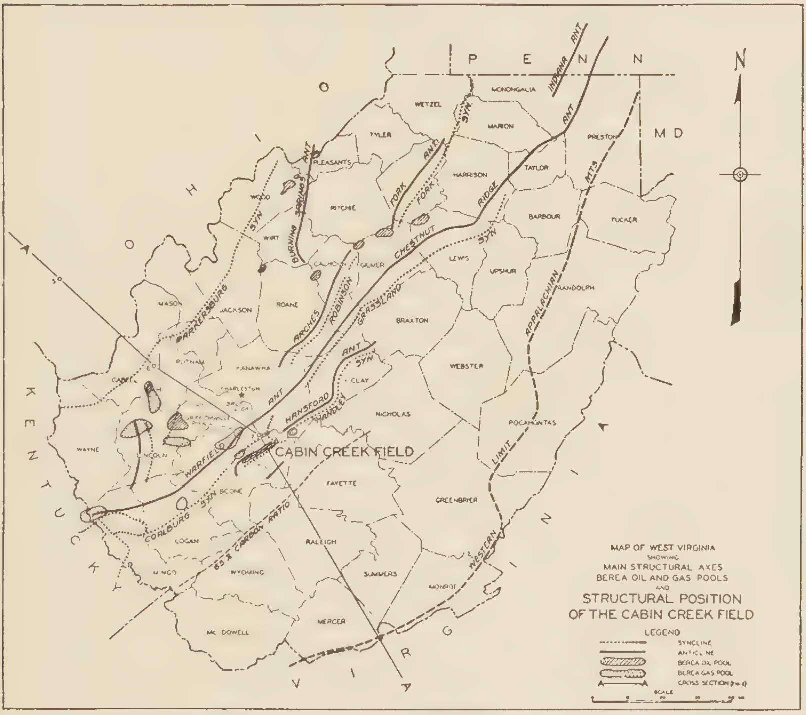


FIG. 1.—Outline map of West Virginia showing main structural axes, Berea oil sand gas pools, and structural position of the Cabin Creek field.

into two equal parts, a northwestern and a southeastern. Cabin Creek is the only pool southeast of the Coalburg syncline. The field lies well down the east slope of the Warfield anticline, which, with Chestnut Ridge, is the longest structure in the state. Cabin Creek is 75 miles northwest of the Appalachian Mountain front. It is 15 miles northwest of the 65 per cent isocarb, which is commonly assumed to indicate the limit of oil production. The 58 per cent isocarb passes through the Cabin Creek field.

OTHER BEREA POOLS

The other Berea oil and gas pools in the state are shown on Figure 1. Cabin Creek stands first in size of production; Griffithsville, in Lincoln County, which is also located in a syncline, is second in size; and the Finck pool in Lewis and Doddridge counties is third. The Berea pools at Belmont, Pleasants County, and Hendershot-Ogden, Woods County, are among the earliest developed in the state. The Newberne and Revere pools in Gilmer County, Richardson pool, Calhoun County, and Milton pool in Cabell County were developed mostly before 1910. The only recently discovered oil pool in the Berea is at Liverpool, Wirt County.

TOPOGRAPHY

Cabin Creek is located on the Allegheny Plateau, which, in this area, is a highly dissected plateau in the mature state of erosion. The summits of the ridges rise to a common level; and on top the true plateau condition is clearly evident, as is shown in Figure 3. The natives call the area mountainous. With the elevations ranging from 800 to 1,600 feet, and with all the land surface in a slope of 20° to 30°, they are not far wrong. Drilling materials are delivered to wells on the ridges by a narrow-gauge railroad. This railroad has been moved several times as the drilling is carried southwestward.

EARLY HISTORY

DRILLING METHODS INVENTED IN THE GREAT KANAWHA VALLEY[1]

It is not generally known that all the essential machinery and methods for oil-well drilling in hard rock really originated in the Great Kanawha Valley, West Virginia, 12 miles northwest of the Cabin Creek field. Salt licks, which occur along the banks of the Kanawha, were frequented from time immemorial by Indian tribes and wild animals. The first white families in this region settled near these licks and boiled the salt water to acquire their meager supply of salt. In 1806, David and Joseph Ruffner set to work to ascertain the source of the salt water and to procure a supply equal to the growing demands of the country. They first set up a large hollow sycamore trunk. By one man with pick and shovel inside, and another man above with bucket and swape to lift the earth out, the hollow tree was lowered 17 feet, where they reached solid rock. In order to go deeper they fixed a long iron drill with a chisel bit and attached the upper end to a spring pole. By welding lengths of shaft to the drill, the hole was deepened during the next two years to 58 feet in the rock where sufficient brine was encountered to run their furnace. In

[1] *West Virginia Geol. Survey*, Vol. 1A, pp. 1–13.

order to get the brine undiluted to the surface, the problem of casing arose. They whittled out two half-tubes of wood, 40 feet long, external dimensions $2\frac{1}{2}$ inches, and wrapped the whole with small twine. This with a skin bag full of flaxseed, wrapped around the base, was pressed cautiously into place and served the purpose perfectly. Thus was the first well in the United States drilled, cased, and packed, 60 years before the first oil well was drilled.

In later wells, tin tubes soldered together replaced the wooden tube for casing. After that copper was used, and finally iron. Soon after this "slips" were devised for use in drilling. These were long, double links with jaws fitting closely together but sliding loosely up and down. These inventions gave great impetus to deep boring in the Kanawha Valley. The deepest well drilled in this early period was 2,000 feet.

EARLY HISTORY OF CABIN CREEK FIELD

In 1914, The Columbus Producing Company, a subsidiary of The Ohio Cities Gas Company, which later became The Pure Oil Company, acquired leases on a block of about 60,000 acres in southern Kanawha and northern Boone counties. They held other scattered tracts through counties to the northeast. This acreage had been taken mainly with the idea of developing gas and without any regard to geological conditions.

The first well, however, was located with care on the southeast flank of the Coalburg syncline, 8 miles southeast of the Warfield anticline, according to the geological map of Kanawha County, published in 1913, by the West Virginia Geological Survey. The location was placed far enough down the structure to have a chance for oil, yet far enough up to have gas possibilities also. When the Berea cap was reached there was a dead oil scum and hard white sand, which made it appear as though the well would be dry. After drilling 10 feet deeper, on December 18, 1914, the bit dropped into soft porous sand, the hole filled with light oil, and there was considerable gas. After a shot the well flowed 214 barrels for the first 24 hours. The well produced until the end of 1924, when it was shut in for gas. This well is located in the northeastern end of the field (Fig. 1), which was drilled up rapidly in the next few years. Later development jumped across Mount Hope, which is the divide between Kanawha and Coal rivers; and some of the best wells in the field have been drilled on Joe's Creek, a tributary of Coal River.

Of the wells drilled by The Pure Oil Company, 268 were oil wells, 6 were gas wells, and only 7 were dry holes. Several of the dry holes were drilled to outline the limits of the pool.

STRATIGRAPHY

PENNSYLVANIAN SURFACE

The rocks of the surface consist of sandstones, shales, and coals of the Allegheny and Pottsville groups of the Pennsylvanian. Benches at coal-bed levels are plentiful and massive sandstones on the hillsides commonly weather "chimney"-fashion. Minor drainage is generally closely related to local dips. The regional dip is northwest, but in the Cabin Creek area this dip is practically overcome by the Warfield anticline and Coalburg syncline. The surface contouring was worked on the Cedar Grove coal of the Allegheny series.

PENNSYLVANIAN SUBSURFACE

The Pennsylvanian rocks are about 1,400 feet thick, and consist largely of sands and thin limes and shales. In this formation the "Grampus," the drillers' term for a hard sand found near sea-level, has an average thickness of 150 feet. The "Salt sand," named from its saline water, is a bed 50 to 75 feet below the "Grampus," and is the basal member of the Pennsylvanian. The unconformity at the base of the Pennsylvanian is not angular, but merely one of erosion. The basal sands have filled in all irregularities on the Mississippian floor.

MAUCH CHUNK

Below the Pennsylvanian is the Mauch Chunk, consisting of characteristic red shales, limestones, and non-persistent sand bodies. The "Maxon" sand belongs to this group. The Mauch Chunk was laid down in the Appalachian geosyncline with successive overlaps to the west, until, at its widest extent, it reached nearly to Ohio River.

GREENBRIER

Conformably below the Mauch Chunk is the Greenbrier limestone, the "Big lime" of the driller, which is equivalent to the Maxville of Ohio The Greenbrier lime consists of the "Little lime" member, about 100 feet thick, the "Pencil Cave," 8 to 20 feet thick, and the "Big lime," 200 feet thick. Drillers sometimes miss the "Pencil Cave" and record the two limes as one. The "Keener" is any sand found within and near the bottom of the "Big lime." Immediately below the lime is the "Big Injun," about 30 feet in thickness. The "Big lime," "Keener," and "Big Injun" may be correlated with the "Big Injun" of northern West Virginia.

POCONO

The Pocono series is about 400 feet thick and includes the "Squaw" and "Wier" sands. Both terms are rather loosely used, since the sands are

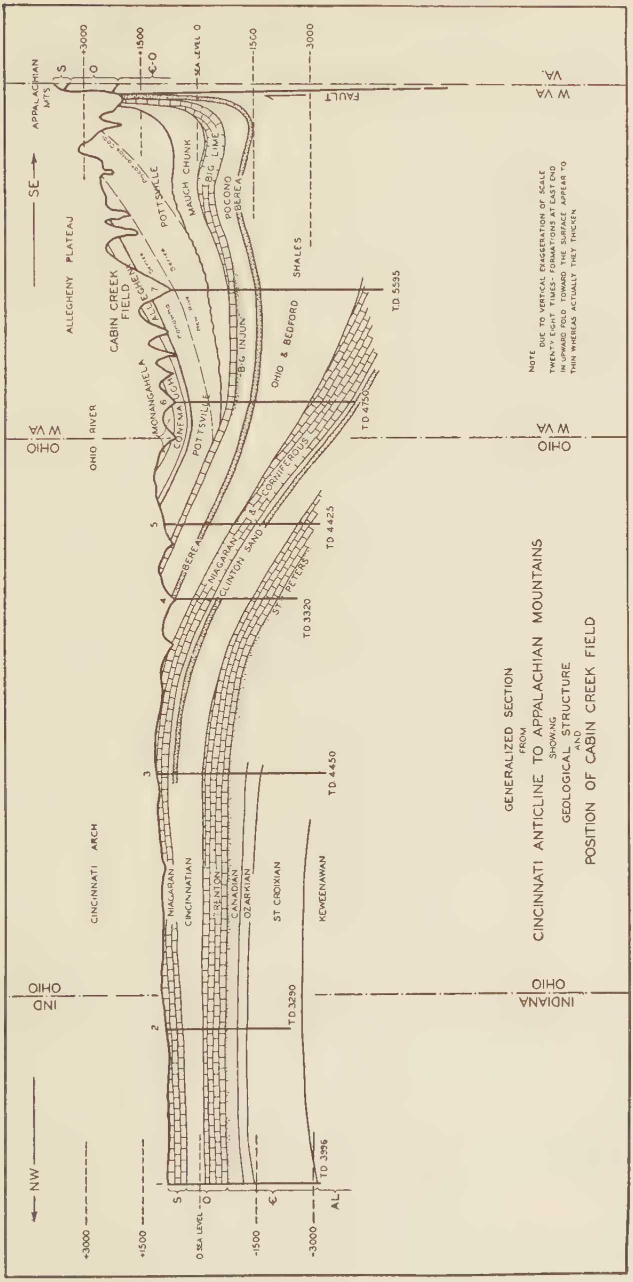

GENERALIZED SECTION
FROM
CINCINNATI ANTICLINE TO APPALACHIAN MOUNTAINS
SHOWING
GEOLOGICAL STRUCTURE
AND
POSITION OF CABIN CREEK FIELD
NOTE
DUE TO VERTICAL EXAGGERATION OF SCALE
TWENTY EIGHT TIMES- FORMATIONS AT EAST END
IN UPWARD FOLD TOWARD THE SURFACE APPEAR TO
THIN WHEREAS ACTUALLY THEY THICKEN
NW
SE
APPALACHIAN MTS
ALLEGHENY PLATEAU
CABIN CREEK FIELD
OHIO RIVER
CINCINNATI ARCH
W VA
VA
OHIO
IND
INDIANA
FAULT
SEA LEVEL 0
+3000
+1500
-1500
-3000
POTTSVILLE
MAUCH CHUNK
BIG LIME
POCONO
BEREA
SHALES
OHIO & BEDFORD
BIG INJUN
ALLEGHENY
MONONGAHELA
CONEMAUGH
CORNIFEROUS
NIAGARAN
CLINTON SAND
ST PETERS
CINCINNATIAN
TRENTON
CANADIAN
OZARKIAN
ST CROIXIAN
KEWEENAWAN
T.D 5595
TD 4750
TD 4425
TD 3320
TD 4450
TD 3290
TD 3996

FIG. 2

not uniform. The "Squaw" is applied to any oil- or gas-producing sand not far above the Berea "Grit." The "Wier" and "Squaw" sands, probably one horizon in Cabin Creek, have good showings of gas generally scattered throughout the area. They are most commonly found in the wells on Joe's Creek.

The Coffee shale, which is equivalent and strikingly similar lithologically to the Sunbury shale of Ohio, occurs immediately over the Berea. This shale is a thin, platy, "stinking," brown shale and is rarely missed by the driller. It is, therefore, an excellent marker for the Berea. Its average thickness is 12 feet.

BEREA

The Berea is the producing sand of the Cabin Creek field, and therefore demands more attention than formations above or below. It is clearly

TABLE I

Deep Wells Used in the Cross Section, Figure 2

Well Name	County and State	Elevation in feet	Reference
1. Greentown*..	Howard, Ind.	840 est.	*Ind. Geol. Survey Bull. 55* (1926) p. 256
2. Bryant*.....	Jay, Ind.	870 est.	*Ind. Geol. Survey Bull. 55* (1926) p. 282.
3. Friend, D.T..	Clark, Ohio	1,100 est.	Not published. Log and samples, Pure Oil Co., Geol. Dept. Location, 11½ mi. SE. Springfield, Ohio.
4. Waverly.....	Pike, Ohio	600 est.	*Amer. Jour. Science*, Vol. 31, p. 19.
5. Martin......	Jackson, Ohio	872	*Ohio Geol. Survey* files.
6. Templeton...	Cabell, W.Va.	585	D. B. Reger, "First Test of Clinton Oil Sand in W. Va.," Feb., 1925, Meeting, *Amer. Inst. Min. and Met. Eng.*, p. 3.
7. Edwards.....	Kanawha, W.Va.	640	*W. Va. Geol. Survey*, Kanawha Co. Rept. (1914), Intro. XVIII.

* Correlation from samples by Dr. Logan, state geologist, Indiana.

a near-shore sand deposit of an advancing sea. It is the basal member of the Mississippian, and is remarkable for its uniform thickness and purity over a very large area. The Berea occurs in West Virginia, Pennsylvania, Ohio, Kentucky, and Michigan, in all of which states it is productive.

At Cabin Creek, the Berea has a range of 15 to 52 feet in thickness, with an average of about 35 feet. It is divided into two parts, cap above and "pay" below. This relation is brought out by Figure 5. The thickness of the cap is uniform in the field, averaging 15 feet, although it thins both northwest and southeast of the field. The cap is clear, white, hard quartz-

ite, drilling always as fine chips, never as grains. The quartzitic structure is evident from the smooth glistening surface of a freshly broken piece. Under the microscope the built-up sand grains, which interlock, are clearly seen. Its porosity, by Melcher's method, gives only 4 per cent.

The "pay" occurs without a break below the cap, and the transition seems to be fairly sharp. The "pay" is 35 feet thick in the best part of the pool but it pinches out on the southeastern side of the field. The limits of the field on the northeast and southwest are controlled by this pinching-out of the "pay." The cap is continuous; the "pay" is a lens below the cap. The deduction follows that where the total Berea thickness is less than 15 feet, it is all cap. The limit of the field on the southeast side is determined by the non-existence of the "pay." The Berea "pay" is pure quartz sand with here and there flaxseed bodies of dark shale. The texture of the sand ranges from very fine-grained to pebbly. The pebbles are small, white, and well rounded. This pebbly phase is erratic, occurring in thin streaks, or patches of small extent. The grains are angular and most of them sparkle under a lens. There is little cement, the sand drilling easily into individual grains. The porosity averages about 16 per cent.

DEVONIAN

Formations below the Berea have been tested by three wells, which were located in the northern part of the Cabin Creek area. None has found any sand which might induce deeper drilling. The deepest test was the Edwards well, No. 7 on the cross section, Figure 2, Table I. This well penetrated nearly 3,000 feet of black Devonian shale below the Berea, and near its total depth of 5,595 feet entered the Corniferous lime. The Bedford shales thicken so rapidly from Ohio toward the Appalachian geosyncline that drilling for Corniferous or Clinton production is very discouraging.

REGIONAL STRUCTURE

Regionally, the Cabin Creek field is located on the eastern slope of the Appalachian geosyncline. The cross section (Fig. 2), whose trace is shown for West Virginia on Figure 1, was made to show the structural relation from the Appalachian front, at East River Mountain, across West Virginia, Ohio, and into Indiana. It is constructed from deep wells, which are tabulated for further reference (Table I) and from surface work along East River Mountain. The surface profile is drawn to scale from United States topographic maps. At the base of this mountain there is a fault, with at least 6,000 feet of throw, since Devonian beds, which are known to be 6,000 feet deep, are brought to the surface, while the mountain on the east side of the fault is composed of Cambro-Ordovician and Silurian

limestones. The dominant features, as brought out by the section, are the restricted basins of sedimentation and the consequent thickening of sediments toward the geosyncline, as indicated especially by the Mauch Chunk and Pottsville and the tilting of these sediments toward the west with the rise and folding of the Appalachian Mountains. The Pocahontas coal indicates the degree of tilting at its maximum. The section shows also that the youngest formations of the Pennsylvanian, the Conemaugh and Monongahela, occur along Ohio River, where the Parkersburg syncline has made for their preservation.

The cross section is extended northwest, mainly on account of the very interesting Friend well (Fig. 2, No. 3). This well was drilled in 1925 and 1926, located high up on the Cincinnati arch. Instead of entering granite below the Magnesian lime, as was expected, it went through nearly 2,000 feet of Cambrian sand and limestones.

STRUCTURE OF CABIN CREEK POOL

The Cabin Creek pool is strictly a monoclinal accumulation, found in the thickened lensed portion of the lower part of the Berea sand, well down

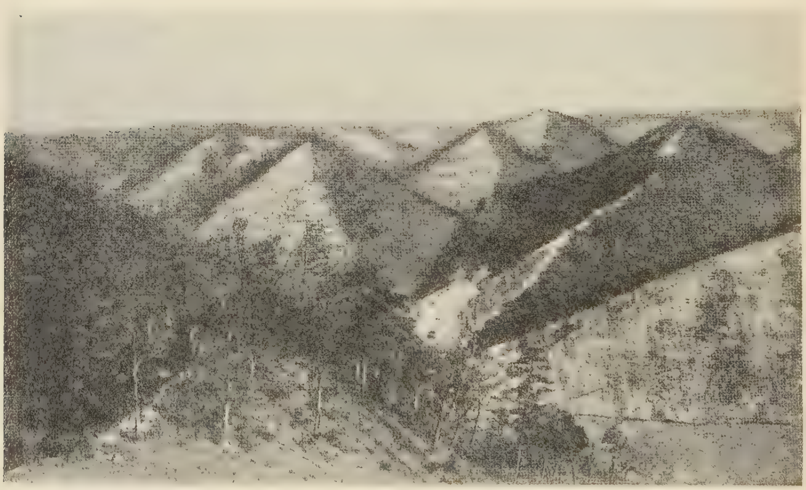


FIG. 3.—Remarkable winter scene on the mountains at Cabin Creek. An imposing scene from the top of one of the mountains above Dawes, West Virginia. Notice the pyramid effect, which was obtained by getting the picture when the sun was at the right place and when there was just enough snow to outline the mountains.

the side of a syncline. The lens extends parallel with the synclinal axis in a long narrow area 12 miles long by $\frac{1}{2}$ to 1 mile wide.

As shown in Plate 1, the surface coal structures at Cabin Creek are not

reflected in the subsurface Berea structures. From the surface axes the pool appears to be located between two subordinate structures, a short anticline and a syncline running along the south edge of the field. On the Berea these structures are not present; neither is the Coalburg syncline, which is located northwest of the field by the West Virginia Geological Survey, and is one of the main surface structures in the state. The Berea does reflect the Warfield anticline, which is about nine miles northwest of the pool. Here the Berea axis is located nearly under the surface axis. The Berea slopes from the crest of the Warfield anticline from −950 feet to −1,800 feet, at the rate of 85 feet per mile, across the Cabin Creek pool, into a basin located about two miles southeast of the field, from which it rises to the Wake Forest anticline, $4\frac{1}{2}$ miles to the southeast, where it has an elevation of −1,550 feet. The pool occurs between the −1,600- and −1,700-foot contours. There are a few minor nosings across the field, which have widened the pool at those points.

ACCUMULATION

The Berea contains no water; therefore the oil fills the lens as far down on the synclinal slope as the pay lens exists. At the upper edge of

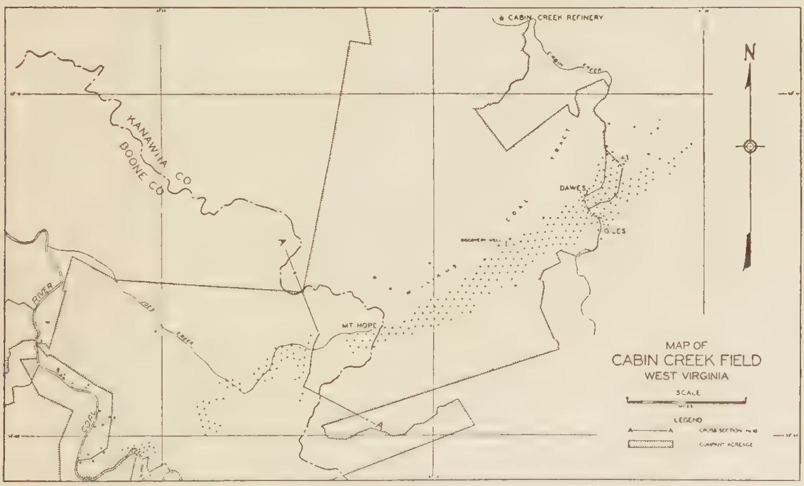
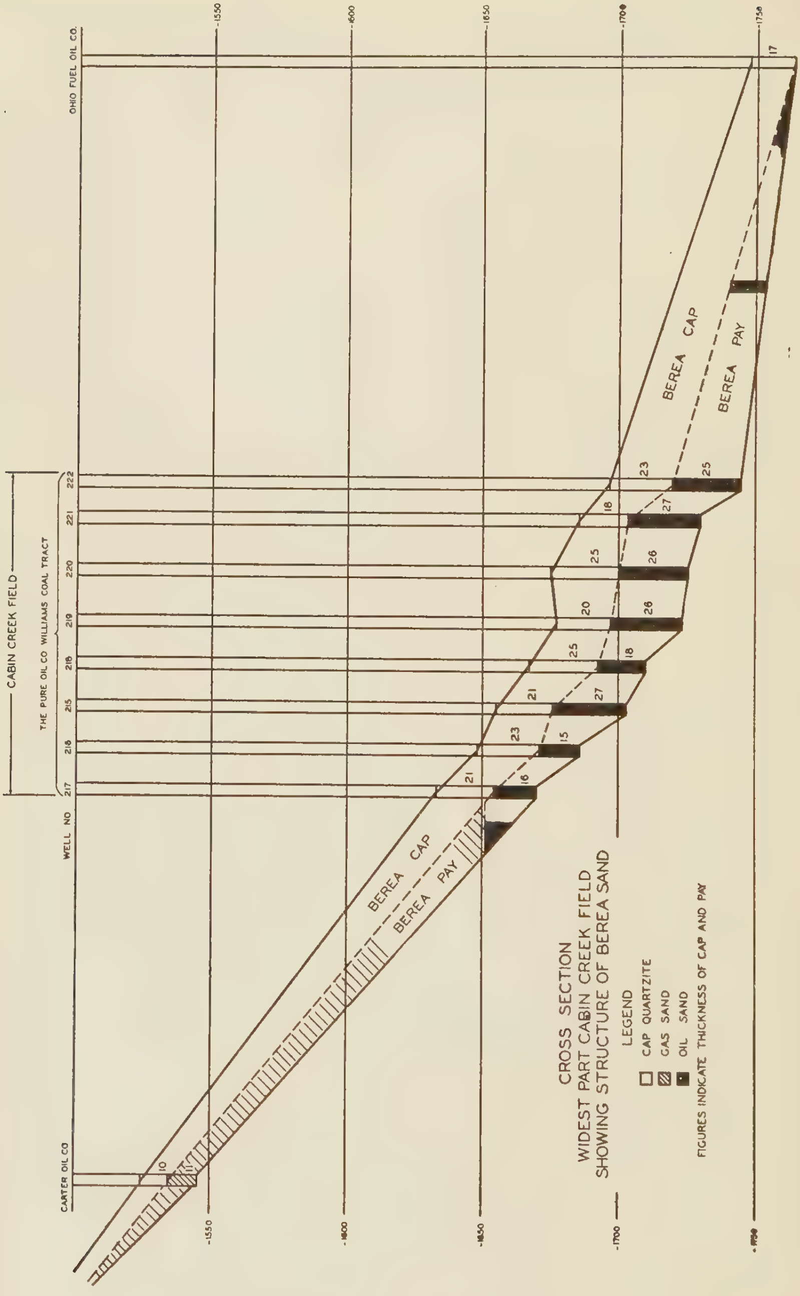


FIG. 4.—Map of Cabin Creek field, West Virginia.

the field gas occurs, and continues some distance toward the Warfield anticline. As there has been little drilling in the gas territory, the upper limit of the gas reservoir is not definitely known. It is located not more



CROSS SECTION
WIDEST PART CABIN CREEK FIELD
SHOWING STRUCTURE OF BEREA SAND
LEGEND
CAP QUARTZITE
GAS SAND
OIL SAND
FIGURES INDICATE THICKNESS OF CAP AND PAY
CABIN CREEK FIELD
THE PURE OIL CO WILLIAMS COAL TRACT
WELL NO
217
216
215
218
219
220
221
222
CARTER OIL CO
OHIO FUEL OIL CO.
BEREA CAP
BEREA PAY
-1550
-1600
-1650
-1700
-1750

FIG. 5

than 2 miles northwest of the pool. Sand conditions and gas, rather than structure, are more important in controlling production at Cabin Creek.

The present rock pressure of wells on the upper side of the field ranges from 20 to 185 pounds, as compared with an original rock pressure in excess of 300 pounds. The present average is about 100 pounds. Existing rock pressures along the southern edge of the field range from 10 to 100 pounds, with an average of about 60 pounds.

The reason for the present lack of water in the Berea is still a problem. This condition is common throughout the Berea of West Virginia except near the western edge. Even in the bottom of the synclines, water is not reported in the Berea. The sand must have had water at the time of deposition, for it is distinctly a marine sand. The lens at Cabin Creek may have been an off-shore deposit. It is possible that an ancient barrier may have existed along the present location of the Warfield anticline which held the shore line stationary during this deposition, for the Berea over the anticline is thin and non-productive. The pebbly streaks in the Berea, and the purity of the quartz are evidence of marine origin. It is also certain that the sand contained water when the upper portion was made into a quartzite. Possibly the water in the lower portion of the lens was stagnant, whereas the upper waters were circulating. Hence the non-porous cap and open "pay."

Probably the oil formed in the Devonian shales and migrated into the Berea sand during the Appalachian revolution. Due to heat, under pressure, the oil may have been distilled and entered the sand largely as a gas, dispelling the water. As the gas cooled, the oil vapors condensed and gathered by gravity down the dip into the lower part of the pay lens, the gas occupying the upper part.

CABIN CREEK OIL

The oil is light amber, clear, and thin, with a strong gasoline odor. Its average gravity is 47° Bé. It has a paraffin base, and on being cooled becomes clouded. By keeping the oil standing in a column over the sand, the paraffining of the sand is not a problem.

The oil is remarkable for its lubricating quality. The ratio of hydrogen to carbon is high, which makes the lubricating oil appreciably more stable under heat than that from other Pennsylvanian grade oils, and it is for this reason largely that it brings a price higher than Pennsylvanian crude.

DEVELOPMENT

WELL SPACING

The well spacing until recent times has been uniformly 700 feet on radial lines at 60° to each other. By this arrangement there was one well

to 9.3 acres. The spacing being used at present is 600 feet, making 7 acres per well. Along the right of way near Dawes, at the northeast end of the field, where some offsets were drilled by other companies, wells were spaced much closer, the average being 200 feet.

PRODUCTION HISTORY

The almost total absence of production data on other eastern pools makes it difficult to show the important position Cabin Creek holds in the East. To those more familiar with the large Mid-Continent pools, the oil yields from Cabin Creek appear to be comparatively unimportant. However, due to the fact that the average price per barrel for Cabin Creek crude has been about twice that obtained for 40° crude in Mid-Continent fields through the same period of years, the net returns to the operator are correspondingly doubled, and the field is given a special significance.

TABLE II

Analysis of Cabin Creek Crude

Gravity 46.7° Be′. Sulphur 0.018 Per Cent

Cut	Grade	Per Cent Crude	Degrees Gravity	Flash	Fire	Vis/100	Pour
Over to 50.4..	Crude naphtha	45	60.1	....	....	....	....
50.4–42.4.....	Kerosene distillate	15	45.3	154	....	....	....
40.6–38.4.....	Gas oil	5.0	38.4	280	325	....	....
38.4–Off......	Wax distillate	18	34.2	360	410	93	70
Bottoms.....	Cylinder stock	13.27	26.9	545	615	155/210	....
Loss.........	....	2.98	....	....	....	....	....

The average cost of drilling the 2,700- to 3,200-foot wells has been about $15,000 per well. With an efficient gasoline plant, with the oil run by gravity lines to the refinery, 4 miles away, this field is a complete unit.

The field can be divided into four main parts: the northeastern, the central, the Joe's Creek, and the Coal River (Fig. 4).

The northeastern end extends from the discovery well northeastward, and includes about 100 Pure Oil, and about 50 outside wells. This portion is completely drilled. The initial production per well, on company acreage, ranges from 10 to 200 barrels, with the exception of a few wells having an initial production as large as 400 barrels. The average initial production was about 50 barrels.

The central part extends from the discovery well to the Boone-Kanawha County line at Mount Hope. This also includes about 100 wells, although it is perhaps only three-fourths developed. This portion is much more productive than the eastern end, with the larger wells along the

upper side. The range for initial production is the same as for the northwestern zone, but with a higher average.

The Joe's Creek part extends from Mount Hope to a point about a mile northeast of Coal River. It includes about 100 wells, but is only about one-third developed. The development along Joe's Creek is the most productive part of the field. It is also most spotted in size of wells. The very large wells seem to be arranged singly, or in small groups, suggesting local sand conditions as being of prime importance.

The wells at the Coal River end are very small, and the oil pool terminates not far below the river.

From a study of the ultimate production per well it is found that the larger wells are located along the upper side of the field, the smaller along the lower side.

DECLINE CURVES

From a study of the rate of decline of the wells it is evident that those most rapidly declining are on the upper side, with the more slowly declining ones on the lower side. This relation holds true everywhere, except from Mount Hope for about two miles along Joe's Creek. In this section, where the largest wells are located, all are slowly declining.

UNIT OPERATION

The development of the Cabin Creek field is an example of what can be accomplished by a single company, or what is, in its essence, unit operation. Development has been definitely regulated to satisfy the needs of the company refinery at Dawes, which fluctuate somewhat, due to market demands. Forced drilling to satisfy offset requirements has been largely avoided. As there is no demand for rapid drilling, information from each new well can be used in making new locations, with the result that dry holes are negligible. Over-production is prevented, gas and oil waste are eliminated, drilling and operating costs are reduced to a consistent minimum, and excess equipment, for short-time use, has been unnecessary.

INDEX[1]

A

[1] Items referring to titles of papers are shown in italics.

C

D

E

F

G

J

K

L

N

R

T

V

W

Y

PRINTED IN U·S·A·

20-1